Weyerhaeuser
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July 17, 2006

Jason Walter
Aquatic Biologist
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Weyerhaeuser
PO Box 9777
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Leslie Schaeffer
Permit Specialist
Protected Resources Division
NMFS
1201 NE Lloyd Blvd.
Suite 1100
Portland, OR 97232-1274

JUL 21 2006

RE: Application for renewal of NMFS permit #1330

Dear Leslie,

This letter and application are being submitted to fulfill the requirements outlined for the renewal of NMFS permit #1330. I have also included all necessary attachments with the application.

Please feel free to contact me at (253) 924-6795 or via email at jason.walter@weyerhaeuser.com if you have any questions or concerns.

Sincerely,

Jason Walter

Jason Walter
Aquatic Biologist

cc: Brian Fransen

A) Title:

Application for Permit for Scientific Purposes under the Endangered Species Act of 1973.

Project Name:

- St. Helens Stream Recovery Research
- Support to "North Fork Toutle Telemetry Project" (Collaborators: USACE, Steward & Associates, USGS, WDFW, Cowlitz Tribe)

B) Species:

- Steelhead (*Oncorhynchus mykiss*)
  - Lower Columbia River ESU
- Chinook Salmon (*Oncorhynchus tshawytscha*)
  - Lower Columbia River ESU
- Coho Salmon (*Oncorhynchus kisutch*)
  - Lower Columbia River ESU

C) Date of Permit Application:

June 13, 2006

D) Applicant Identity:

1) Jason Walter, Aquatic Biologist

2) Weyerhaeuser Company

3) WTC-1B10
PO Box 9777
Federal Way, WA 98063-9777

4) (253) 924-6795

5) (253) 924-6736

6) jason.walter@weyerhaeuser.com

E) Information on Personnel, Cooperators, and Sponsors:

1) Principal Investigator and Field Supervisor
Jason K. Walter
jason.walter@weyerhaeuser.com
(253) 924-6795
resume attached

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Field Supervisor
John T. Heffner
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(360) 330-1728
resume attached

2) Due to the fact that much of our summer field support comes from seasonal employees and interns, and the potential of contracting for sampling support, we are unable to provide a more complete list of field personnel at this time.

3) All research activity described within this permit application is funded by Weyerhaeuser Company.

4) All research sampling is and will be conducted and/or directly supervised by the permittees listed in Section E.1 of this application.

5) If incidental mortality of an individual of a listed species does occur, specimens can, upon request, be made available to the appropriate university or agency. In the event that such a request is not made, any 'mortalities' will be returned to the body of water from which they were sampled.

6) N/A

F) Project Description, Purpose, and Significance:

1) As a major private landowner with a responsibility and commitment to maintain high quality habitat and healthy aquatic communities, Weyerhaeuser conducts aquatic sampling for the purpose of scientific research. Our objective is to produce and communicate reliable technical and scientific information to support the development and implementation of effective forest management practices and regulations, and to advance the state of the scientific information required to protect aquatic habitat and contribute to the recovery of listed species. NMFS has indicated that a Section 10(a)(1)(A) permit is required for all of our aquatic sampling activities within ESU's containing listed fish species.

   Weyerhaeuser Company employs a team of aquatic scientists and technicians who conduct field studies to develop an understanding of basic relationships between aquatic biota and their habitats, including how forest management prescriptions and restoration activities influence aquatic biota and their habitats. Our research findings are intended for publication in peer reviewed literature. Results are shared with regulators, agencies, and other public resource stakeholders to ensure that management policies and regulations are based on sound technical information.

   Listed steelhead and coho salmon naturally occur in only one of our research sites. Other research sites are located above barriers to anadromous fishes and/or are located in areas that do not contain listed fish.

   Populations and species of ESA listed fishes as well as unlisted populations will benefit from our research as it provides new information relating to the response of freshwater habitat to natural and anthropogenic disturbances. A better understanding of these processes will contribute to the development of recovery plans for listed ESU's.

   Current Weyerhaeuser research projects that may result in the 'take' of a species listed by NMFS include:

Mt. St. Helens Stream Recovery Research

Developing an understanding of how natural recovery processes following large environmental disturbances influence fish and aquatic habitat can lead to better management of these resources. Since 1983 Weyerhaeuser has monitored the recovery of fish populations and physical habitat in streams that were impacted by the eruption of Mt. St. Helens and the subsequent debris torrents that followed.

The primary objectives of this research are to examine the recovery of fish and habitat in streams where catastrophic environmental disturbances have occurred, to determine the factors most responsible for influencing recovery rates, and to identify opportunities where intervention can accelerate recovery rates.

Data describing population and habitat recovery processes collected over long timeframes are rare. Weyerhaeuser aquatic research at Mt St Helens has been ongoing since 1983 and has produced some unanticipated results (e.g. the rate at which high levels of productivity were re-established in streams impacted by the eruption). We also have been able to demonstrate that the patterns of change observed at the Mt. St. Helens sites are comparable to the patterns of recovery seen following less dramatic disturbance events, such as debris torrents. Thus, this research provides an improved understanding of natural recovery processes and can help managers and regulators better determine the consequences to fish populations of various types of perturbations.

North Fork Toutle Telemetry Project

In response to the 1980 eruption of Mount St Helens, the USACE constructed a Sediment Retention Structure (SRS) on the North Fork Toutle River to reduce downstream transport of sediment. The SRS was constructed without fish passage and is currently a barrier to migrating adult salmonids. To facilitate passage, a Fish Collection Facility (FCF) was constructed one-mile downstream of the SRS, where adult steelhead and coho, both threatened species under the ESA, are collected and released upstream of the SRS. The necessity to alleviate fish passage problems associated with the SRS and FCF, which is the top priority within the Lower Columbia Salmon Recovery Plan for the Toutle watershed (LCFRB 2004), lead to the collaboration of the USACE, USGS, Cowlitz Tribe, WDFW, and various stakeholders to develop a proposal to assess the feasibility of various fish passage alternatives. This assessment project will be conducted with the goal of allowing the USACE to determine the most biologically sound approach for increasing the abundance and distribution of coho and steelhead in the North Fork Toutle River watershed upstream of the Sediment Retention Structure (SRS).

Adult fish collected at the FCF have and will continue to be radiotagged by the USGS. Post-release movements of radiotagged wild coho and steelhead will be tracked by the USGS to measure the efficiency of the FCF, determine current passage limitations through the SRS spillway under a range of flow conditions, and identify important biological and physical factors influencing the movement and behavior of radiotagged fish throughout the watershed. Radiotelemetry information will be combined with engineering feasibility-level alternatives for fish passage improvements to the SRS and FCF. The project will conclude with the selection of a preferred alternative for either providing fish passage through the SRS or improving operation of the FCF, or perhaps both. These actions are deemed necessary and prudent for achieving fish passage and, ultimately, fish recovery goals in the Toutle watershed. Development and selection of fish passage modification alternatives at the SRS will be the responsibility of USACE and Ed Zapel, the fish passage engineer for the project. All project team members will be able to provide input, including USGS, Steward and Associates, Cowlitz Tribe, WDFW, etc.

2) Our research activities in Washington State are conducted to support the Forest and Fish Report, which both NMFS and USFWS have endorsed. Adaptive management provisions of that agreement provide for modification of forest management prescriptions in response to new or better technical information. Data collected during our aquatic sampling is being used in this adaptive management process. In addition we make our data available to Federal agencies to aid in their ongoing evaluation of the efficacy of the management approach in the Forest and Fish Report. We also have provided our data in response to requests for data by NMFS and USFWS in support of their Endangered Species Act listing decisions.

3) The Forest and Fish Report is a key component of the Governor's strategy to recover listed fish stocks in Washington State. The adaptive management provisions of Forest and Fish provide a means to bring information we collect into a large collaborative research program. We contribute data and technical support to that process. Publication of our research findings in peer reviewed literature provides a means to communicate technical information to a broad audience of resource managers, scientists, and stakeholders.

4) Much of our research is conducted collaboratively with agencies, universities, and other research organizations. We always have the intention of sharing our results within the scientific and regulatory communities as indicated above. To minimize redundant or needless sampling effort, we do not initiate research projects where sufficient information exists to answer the research question at hand. Thorough review of available literature is a standard pre-requisite of our research project initiation process. Projects only arise when there is a clear need to

collect information that answers carefully formulated questions where no other source of information exists.

Specific to this permit, the North Fork Toutle Telemetry Project is a collaborative effort with USACE, USGS, Cowlitz Tribe, WDFW, and various stakeholders.

5) <u>Mt. St. Helens Stream Recovery Research</u>
Research was initiated in 1983 in the Mt. St. Helens area in response to the 1980 eruption. This eruption removed all vegetation and deposited enormous quantities of fine ash on entire drainages in the vicinity of the volcano. A number of studies were conducted to assess the short-term impact of the eruption on watershed and stream structure and function. However, our work is the only study that has continuously monitored the performance of juvenile salmon and trout in 3 watersheds affected by the eruption (see attached PDF of book chapter "Ecological Responses to the 1980 Eruption of Mt. St. Helens). Few if any studies of fish and habitat recovery processes have been conducted in such circumstances. Long-term monitoring of fish populations and their habitat can lead to improved understanding of the natural capacity of populations and their habitat to recover from such large-scale disturbance. This type of long-term information also is vital in improving our understanding of the relationship between habitat quality and fish population performance. Due to the unique circumstances of the eruption and the long-term nature of the ongoing data collection, no alternative exists to obtain this type of data. Of the three sites we monitor annually, only one (Herrington Creek) is 'naturally' accessible to listed fish species. However, adult coho salmon and steelhead are transported into our study reach on Hoffstadt Creek, upstream of a natural barrier that prevents anadromous fish from accessing the stream reach on their own.

Populations of recently listed steelhead in the Herrington Creek sample reach have exhibited relatively high densities over the past 22 years (see Tables included within Section H-1 of this permit application). State agencies allow for fisheries targeting listed adult steelhead to continue within in the drainage, suggesting that the population is healthy enough to withstand direct take of adult fish by anglers (catch and release fishing). Our sub-sampling methods are designed to minimize the number of fish encountered. If the status of the listed population within our study site declines to a level where our activities may jeopardize the population, we will voluntarily discontinue our sampling in this location.

<u>North Fork Toutle Telemetry Project</u>
We are working with external collaborators on the North Fork Toutle Telemetry Study to identify opportunities to supplement their research with juvenile sampling. This study location, with the effect of the previous

eruption, and the presence of the Sediment Retention Structure on the North Fork Toutle River offers a unique research location that cannot be duplicated elsewhere.

The Lower Columbia Fish Recovery Plan (LCFRB 2004) documents that populations of coho salmon and steelhead in the North Fork Toutle River watershed are at a precarious state. Production from areas above the SRS is dramatically lower than historical levels, and falls far short of levels that could be supported by extant habitat. Excessive sedimentation, mechanical failure, and ill-advised trapping, transportation, and release operations are endangering the future success of the operation, and lowering the prospects for recovery. If issues are not addressed soon, the collection and transport of adult salmonids at the FCF may cease to be a viable option for populating the upper watershed. Retrofitting the SRS spillway to enable volitional passage may offer a practical (and biologically sound) alternative to trap and haul; the research will assess the relative merits of various fish passage options through the SRS.

G) Project Methodology:

1) Initial research sampling in the region around Mt. St. Helens was conducted in Herrington Creek in 1983, three years after the eruption. It is our goal to continue sampling within our three St. Helens study reaches until trends in fish population, stream temperature, and physical habitat recovery have stabilized. Sampling as part of the North Fork Toutle River Telemetry Study will begin this year (2006) and is planned through 2009. Juvenile fish sampling will be conducted with a backpack electrofisher, and all sampling will follow the guidelines as outlined in the "NMFS Backpack Electrofishing Guidelines" from June, 2000. Surveys will be conducted on both projects twice a year, with the first sample being conducted in mid to late June and the second in late September to early October. Two samples are collected (annually) in order to provide us with the data to estimate summer growth, production, and survival.

2) a. Electrofishing surveys are conducted when we require quantitative information characterizing population abundance, species composition, and individual growth rate and size. Sampling for the Mt. St. Helens and Telemetry studies provide this type of information. Electrofishing guidelines provided by NMFS are followed. Aquatic population surveys are conducted via a stratified sub-sampling of habitat units, reducing the stream area where sampling is necessary to obtain an accurate density estimate. Approximately 10% of the habitat units within any given sample area are surveyed. The selected channel units are block-netted, and a 3-pass removal is conducted with a backpack electrofishing unit. All fish captured are measured. We weigh a sub-sample of the fish to minimize handling.

Fish are returned to the stream unit from which they were sampled immediately after being handled.

b. Two separate juvenile fish samples for each of the following sites are scheduled annually, one for mid to late June, and one for late September to early October. Stream sites include all fall within the Columbia River, Toutle River basins and include:

- North Fork Toutle River, Hoffstadt Creek (T10N, R3E, Sec. 23)
- Green River, Schultz Creek (T10N, R4E, Sec. 10)
- South Fork Toutle River, Herrington Creek (T9N, R3E, Sec. 28)
- North Fork Toutle River, Bear Creek (T10N, R3E)
- North Fork Toutle River, Alder Creek (T10N, R2E)

c. N/A

d. We use MS-222 to anesthetize fish, on an as needed basis, prior to handling.

e. During population surveys, sampled individuals are temporarily held in 5-gallon buckets containing stream water. Holding water is aerated and/or changed frequently. Holding time is typically 5 minutes or less and fish are returned to the stream-unit from which they were sampled after being measured and/or weighed.

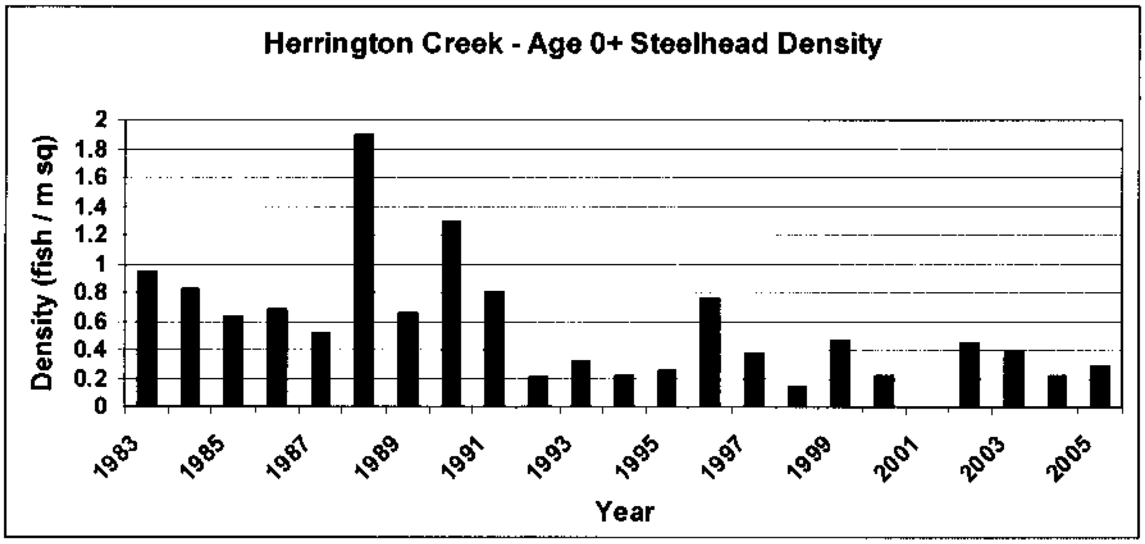
f. N/A

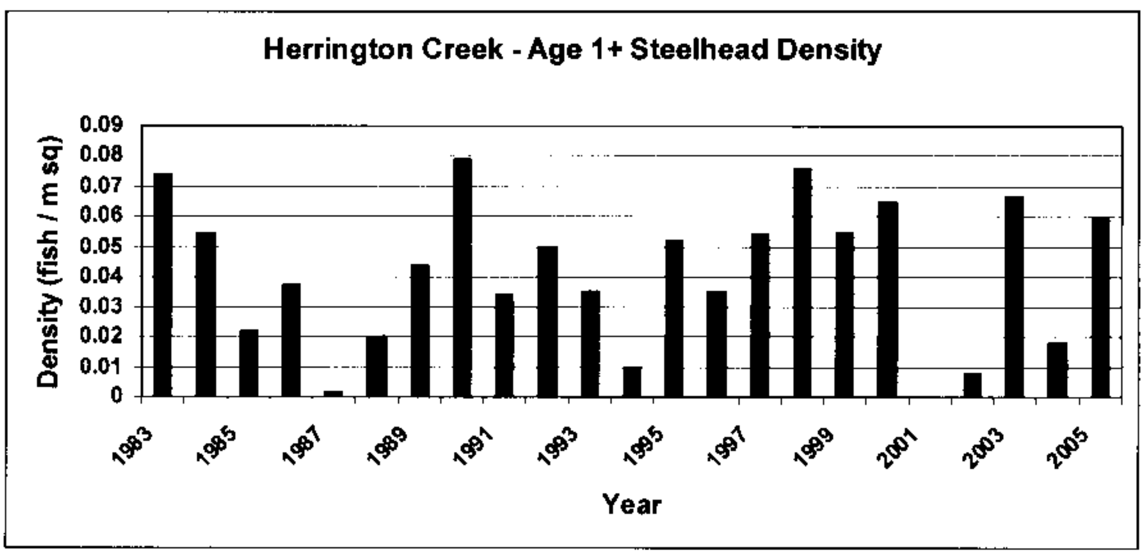
3) For the purposes of research, we employ alternative (to electrofishing), lower risk sampling methods when possible (e.g. snorkeling, visual observation). We handle fish only when quantitative information is required. We also minimize handling risks by measuring and/or weighing only a sub-set of fish captured.

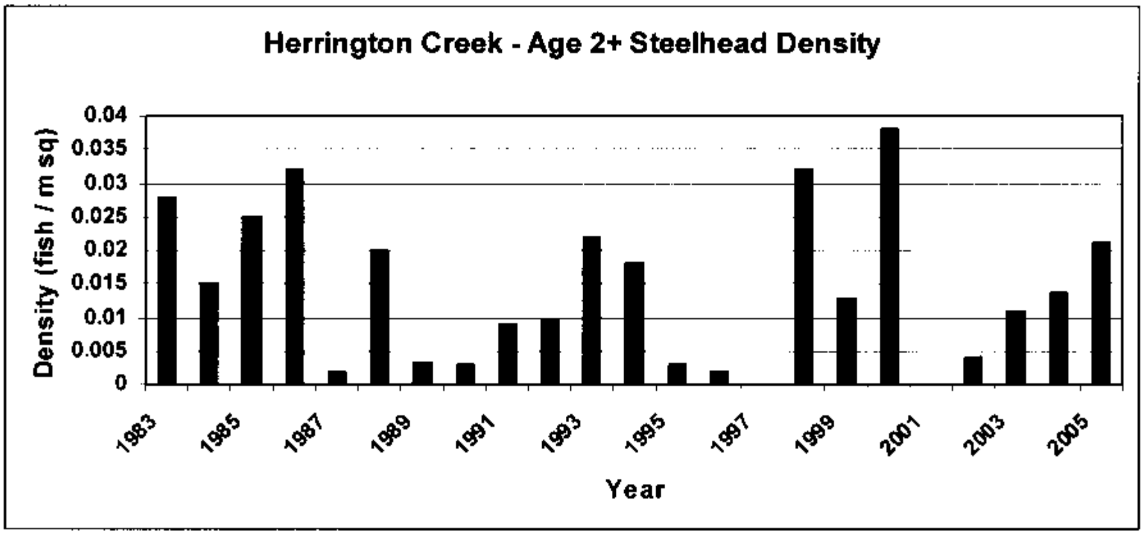
4) Unintentional injury and/or mortality does occasionally occur when electrofishing. Every precaution is taken to minimize the impact of our sampling on all aquatic organisms. We attempt to select research areas where sensitive or listed species are not known to occur. We avoid sampling during times when aquatic organisms would be most vulnerable to our activities (e.g. during incubation, in turbid water). We avoid sampling habitats where we may expose aquatic organisms to a high risk of injury or mortality (e.g. areas where visibility is obscured). We follow the electrofishing guidelines provided by NMFS (June 2000) and the provisions of the WDFW state sampling permit to minimize risk to aquatic life.

H) Description and Estimates of Take:

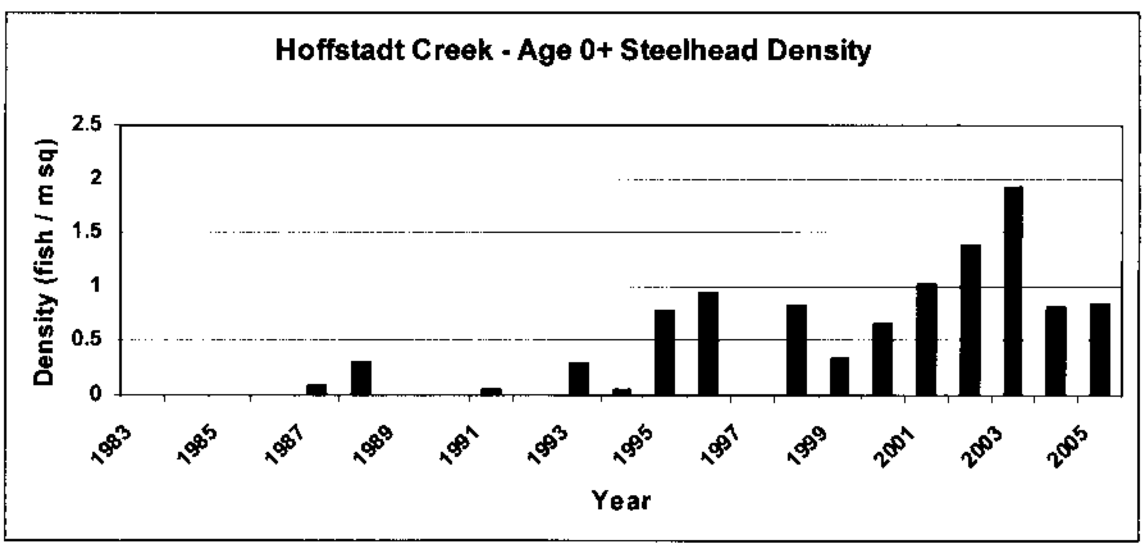
1) <u>Steelhead (*Oncorhynchus mykiss*) - Lower Columbia River ESU</u>
Late summer steelhead abundance within the Herrington Creek study reach over the past 22 years is summarized in the following 3 charts (note - no data was collected from Herrington Creek in 2001):





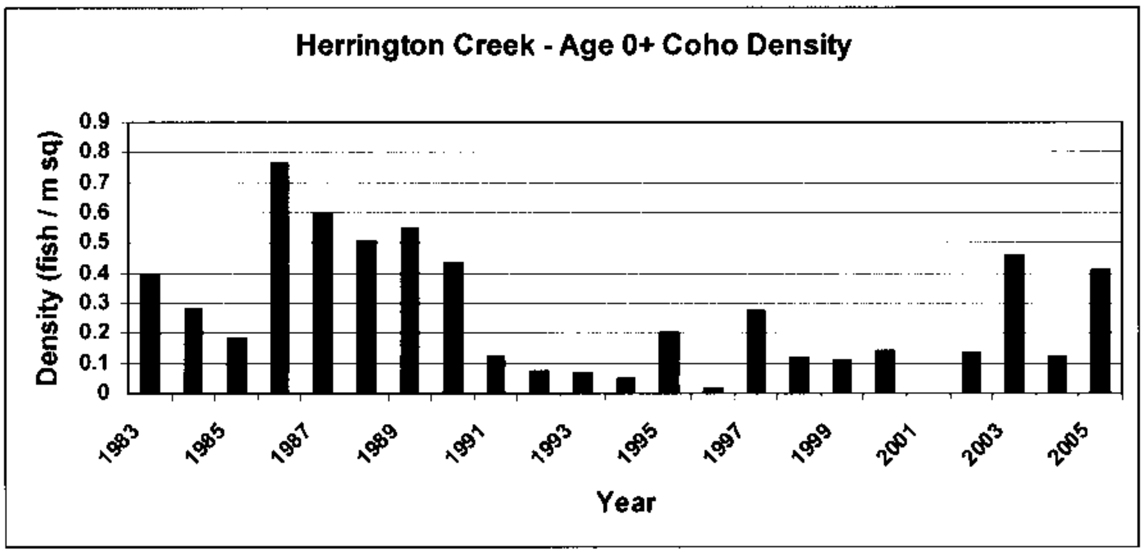


Steelhead populations within Herrington Creek are variable from year to year, with an increasing trend observed in older age-class representation in recent years. This trend may be the result of habitat recovery processes creating conditions more suitable for older, larger fish. Stream temperature and physical habitat are approaching conditions typically observed in forested watersheds not influenced by recent catastrophic disturbance. An apparent declining trend in age 0+ steelhead abundance may be related to decreases in primary production due to increased shading of the stream, declines in adult spawning, and/or the cessation of hatchery stocking of fry that was prevalent in the years immediately following the eruption. Further research is intended to assess factors influencing these population trends.



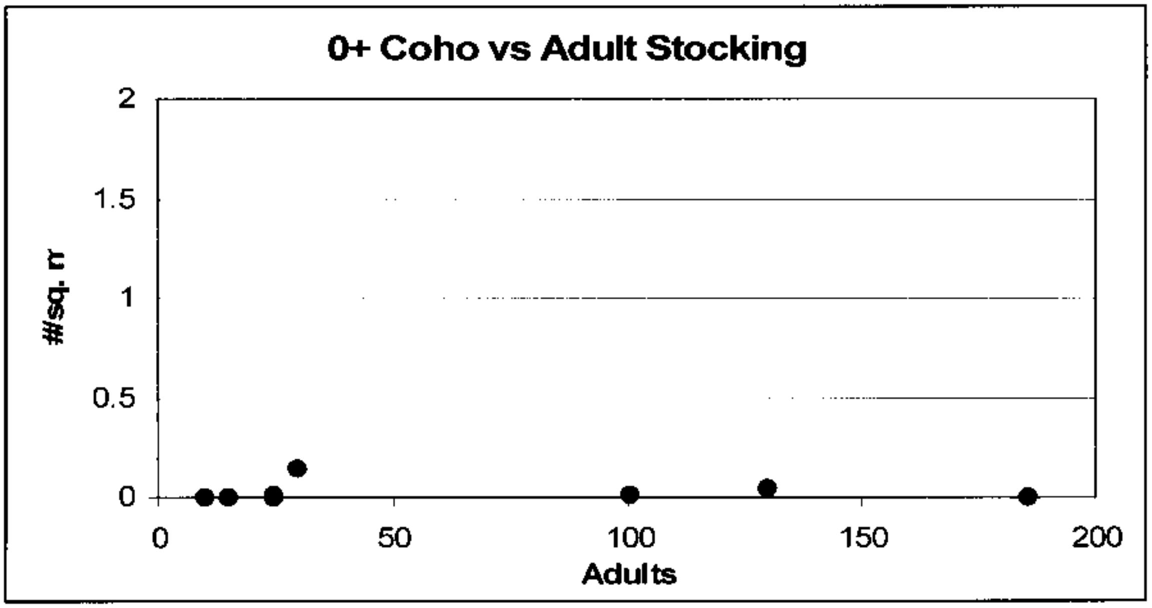
Young of the year steelhead populations within Hoffstadt Creek are variable from year to year, with an increasing trend observed in recent years. This increase in steelhead density can be directly attributed to stocking of adults from the trap and haul program associated with the sediment retention structure to the Hoffstadt Creek study reach. It should be noted that the Hoffstadt Creek study reach is upstream of a barrier to anadromous fish, and there is no 'natural' access of steelhead to the stream reach.

Coho Salmon (*Oncorhynchus kisutch*) - Lower Columbia River ESU
Late summer coho salmon abundance within the Herrington Creek study reach over the past 22 years is summarized in the following chart (note - no data was collected from Herrington Creek in 2001):



Coho populations within Herrington Creek are variable from year to year, with an increasing trend observed in recent years. High coho salmon densities seen in the 1980's can be primarily attributed to hatchery stocking of coho fry at the site.

Recent stocking of coho salmon adults in Hoffstadt Creek (upstream of the natural barrier waterfall) has not resulted in high juvenile coho densities at the time of our late summer sampling (see figure below). Stocking of juvenile coho salmon within this same reach, in the early 1980's, suggested that the stream could support populations of juvenile coho salmon. Therefore, reasons for this trend will be investigated as part of the North Fork Toutle Telemetry Study.



Chinook Salmon (*Oncorhynchus tshawytscha*) - Lower Columbia River ESU

We have, on occasion, encountered a lone juvenile Chinook salmon at one of our survey locations (Herrington Creek). They have been included in this permit application so that in the event that an individual(s) is present we do not need to terminate our regular sampling

2) Justification for Sampling Mortality

All mortalities of listed species that occur during our sampling are indirect. Unintentional injury and/or mortality can occur when electrofishing. However, every precaution is taken to minimize the impact of our sampling on aquatic organisms. Our stratified sampling protocol enables us to obtain a density estimate by sampling approximately 10% of the individuals within a given study reach. Previously collected data indicates that less than 1% of individuals we capture die. Therefore, given the 10% sub-sampling method we employ and 1% expected mortality of individuals captured, an estimate of mortality risk to the population within our sample area would be less than one in one thousand individuals present (0.1%)

3) Proposed Annual Indirect Mortality

These numbers are equal to limits set in our current NMFS permit (#1330) and represent 1% of the total authorized annual take for each listed species. As stated in Section H.3, previous data suggests that the mortality rate from juvenile population sampling with a backpack electrofisher is ≤1%.

Species	Life Stage	Take Activity	Origin	#	Research Location	Research Period
LCR Steelhead	juvenile	capture, handle, release	naturally produced	15	Toutle River Basin, WA	January – December
LCR Coho	juvenile	capture, handle, release	naturally produced	8	Toutle River\ Basin, WA	January – December

4) While Weyerhaeuser currently holds a permit from the USFWS (Permit # TE037785-1) to cover aquatic sampling in areas containing listed species within their jurisdiction, we have not found these species to occur in areas that will be sampled under the proposed NMFS permit.

I) Transportation and Holding:

1) N/A

2) N/A

3) N/A

J) Cooperative Breeding Program:

To the best of our ability, Weyerhaeuser Company is willing to participate in a cooperative breeding program and to maintain or contribute data to a breeding program, if such action is requested.

K) Previous or Concurrent Activities Involving Listed Species:

1) Weyerhaeuser has maintained a Washington Department of Fish and Wildlife – Scientific Collection Permit for over 20 years (Year 2006 Permit # 06-157).

Weyerhaeuser currently holds a permit from the USFWS (Permit # TE037785-1) to cover aquatic sampling in areas containing listed species within their jurisdiction.

Weyerhaeuser currently holds three incidental take permits: PRT-796822 (02/14/1995) covering spotted owls in our Millicoma Tree Farm in SW Oregon, PRT-809072 (07/11/1996) covering the American burying beetle in Oklahoma, and PRT-811415 (08/16/1996) for Red Hill's Salamander in

Alabama. Weyerhaeuser also holds Permit 23304 (09/26/2005) which is a Federal Bird Marking and Salvage Permit.

2) a. Steelhead (*O. mykiss*) – juvenile - Lower Columbia River ESU
Coho salmon (O. kisutch) – juvenile Lower Columbia River ESU

b. All mortalities from the last five years were indirect and the result of population sampling, with a backpack electrofisher, for the purpose of scientific research.

Year	Steelhead Mortalities	Coho Mortalities
2002	1	1
2003	2	2
2004	1	0
2005	2	0
2006	0	0
5 Year Total	7	3

c. In an attempt to eliminate and/or minimize sampling mortality, we attempt to select research areas where sensitive or listed species do not occur. We also avoid sampling during times when aquatic organisms would be most vulnerable to our activities (e.g. during incubation, in turbid water). We avoid sampling habitats where we may expose aquatic organisms to a high risk of injury or mortality (e.g. areas where visibility is obscured). We follow the electrofishing guidelines provided by NMFS to minimize risk to aquatic life. We employ other, lower risk methods when possible (e.g. snorkeling, visual observation). We handle fish only when quantitative information is required. We minimize handling risks by measuring and/or weighing only a sub-set of sampled individuals.

L) Certification:

"I hereby certify that the foregoing information is complete, true and correct to the best of my knowledge and belief. I understand this information is submitted for the purpose of obtaining a permit under the Endangered Species Act of 1973 (ESA) and regulations promulgated thereunder, and that any false statement may subject me to the criminal penalties of 18 U.S.C. 1001, or to penalties under the ESA."

Jason Walter — 7/17/06

Signature — Date

Jason K. Walter, Aquatic Biologist

M) Length of Time and Cost to Prepare Application (Optional)

1) Approximately 15 hours

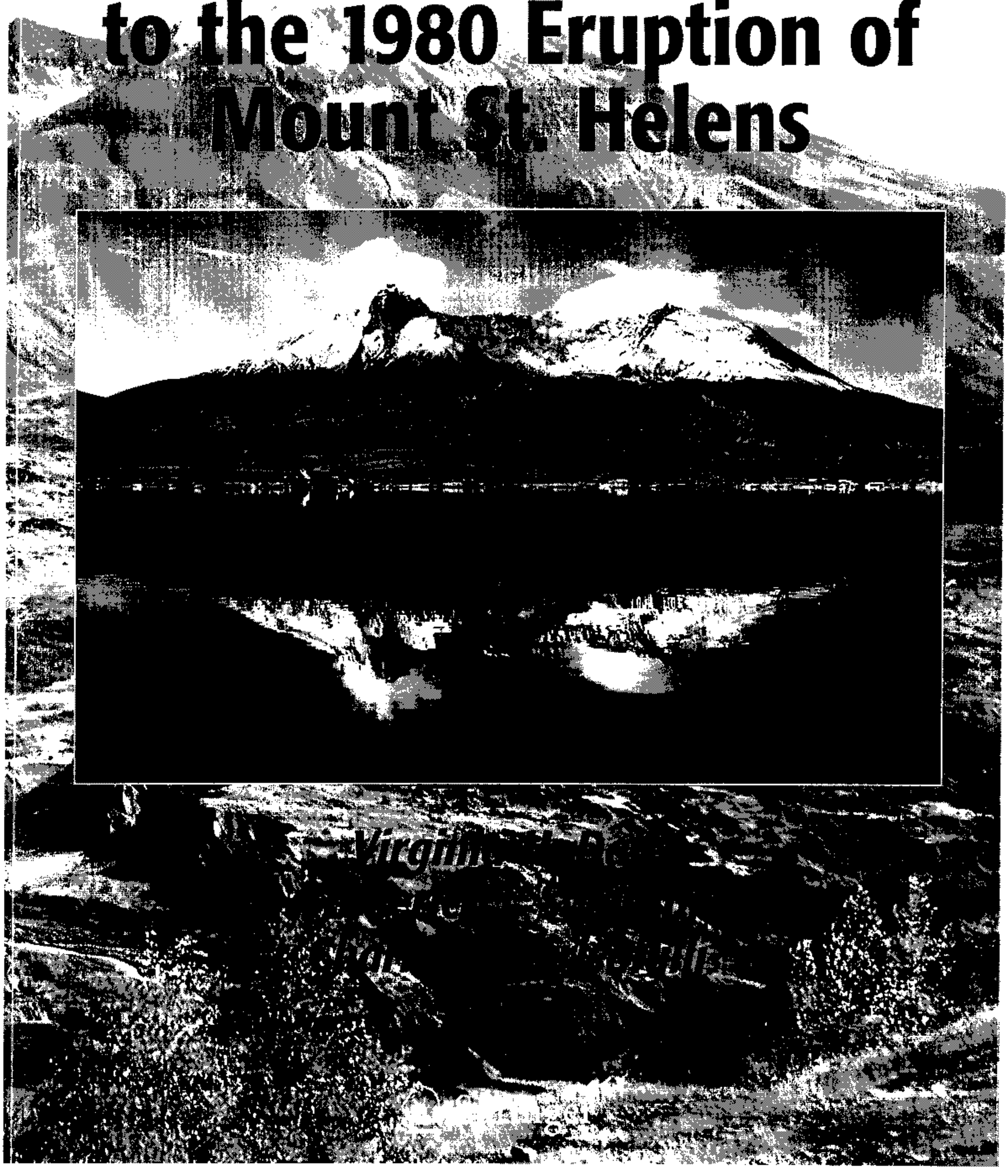
2) Approximately $900

Anticipated Annual Take

Species	Life Stage	Origin	Take Activity	# of Fish Requested	Authorized Unintentional Mortality	Research Period	Location
LCR Steelhead	juvenile	naturally produced	capture, handle, release	1500	15/1500	January – December	Toutle River Basin, WA
LCR Coho	juvenile	naturally produced	capture, handle, release	800	8/800	January – December	Toutle River Basin, WA
LCR Chinook	juvenile	naturally produced	capture, handle, release	5	0/5	January – December	Toutle River Basin, WA

Please note, requested take numbers for steelhead are equal to those specified in our recently modified NMFS sampling permit (#1330) that we received in February of 2006. The increase in requested take for coho salmon is to address both the inclusion of the North Fork Toutle Telemetry Study, and also the recent transporting of adult coho salmon into one of our long-term study reaches, Hoffstadt Creek, which is part of the Mt. St. Helens Recovery Study.

Ecological Responses to the 1980 Eruption of Mount St. Helens



12
Responses of Fish to the 1980 Eruption of Mount St. Helens

Peter A. Bisson, Charles M. Crisafulli, Brian R. Fransen, Robert E. Lucas, and Charles P. Hawkins

12.1 Introduction

Fish are important components of the Mount St. Helens aquatic system. Historically, no other region of Washington State supported as many native freshwater and anadromous species (anadromous fish mature in the ocean but spawn in freshwater) as did the region near Mount St. Helens (Table 12.1; McPhail 1967; McPhail and Lindsey 1986). Many of the anadromous species, including Pacific salmon (*Oncorhynchus* spp.) and eulachon (*Thaleichthys pacificus*), are keystone species that provide an important trophic link between aquatic and terrestrial ecological systems and are the foci of food webs that depend on marine-derived nutrients (Willson and Halupka 1995; Bilby et al. 1996; Levy 1997; Cederholm et al. 2001). In addition, fish are important consumers within rivers and lakes and can influence the species composition and structure of biological communities of these aquatic systems through herbivory, predation, and competition (Power 1990).

Rivers and lakes near Mount St. Helens have traditionally been managed as separate entities by the Washington Department of Fish and Wildlife and its predecessor agencies. The emphasis for lakes has been to manage primarily for recreational fisheries. The emphases in rivers have been (1) to manage salmon for commercial harvest and angling and steelhead (*Oncorhynchus mykiss irideus*) and sea-run coastal cutthroat trout (*O. clarkii clarkii*) for sport harvest and (2) to assure adequate reproduction of wild stocks. Some of this harvest has occurred at sea or in the Columbia River. Although fisheries-management strategies differed between streams and lakes, fish have often moved from one environment to the other. Because most lakes have tributaries with barriers to upstream migration, the majority of movement has probably been from lake to stream rather than the reverse. These barriers proved especially important in the aftermath of the 1980 eruption.

The streams and lakes surrounding the volcano are numerous and diverse with respect to physical habitat and biological communities. Streams range from small, steep, cascade-dominated mountain channels to large, floodplain rivers (e.g., the Cowlitz River and Lewis River). Lakes range from high-elevation, cool, subalpine lakes that are common north of the mountain to low-elevation, relatively warm systems [e.g., Silver Lake (which is discussed in Chapter 2 and Chapter 18 of this volume)]. They were subjected to an array of volcanic disturbances during the 1980 eruption that ranged from the relatively low-level impacts of a few centimeters of tephra fall to burial of an entire river drainage or lake beneath the enormous debris-avalanche deposit (see Swanson and Major, Chapter 3, this volume).

In this chapter, we address five questions.

1. Did fish survive the initial impacts of the 1980 eruption, and, if so, what factors aided their survival?
2. Were fish able to recolonize streams and lakes during the ensuing 20 years, and, if so, by what means?
3. What were the key factors influencing fish survival and growth in posteruption streams?
4. What role did management play in reestablishing fish populations? and
5. Are there lessons from fish responses to the 1980 eruption that could be applied to other managed landscapes?

These questions are addressed first for fish in streams and rivers and then for fish in lakes.

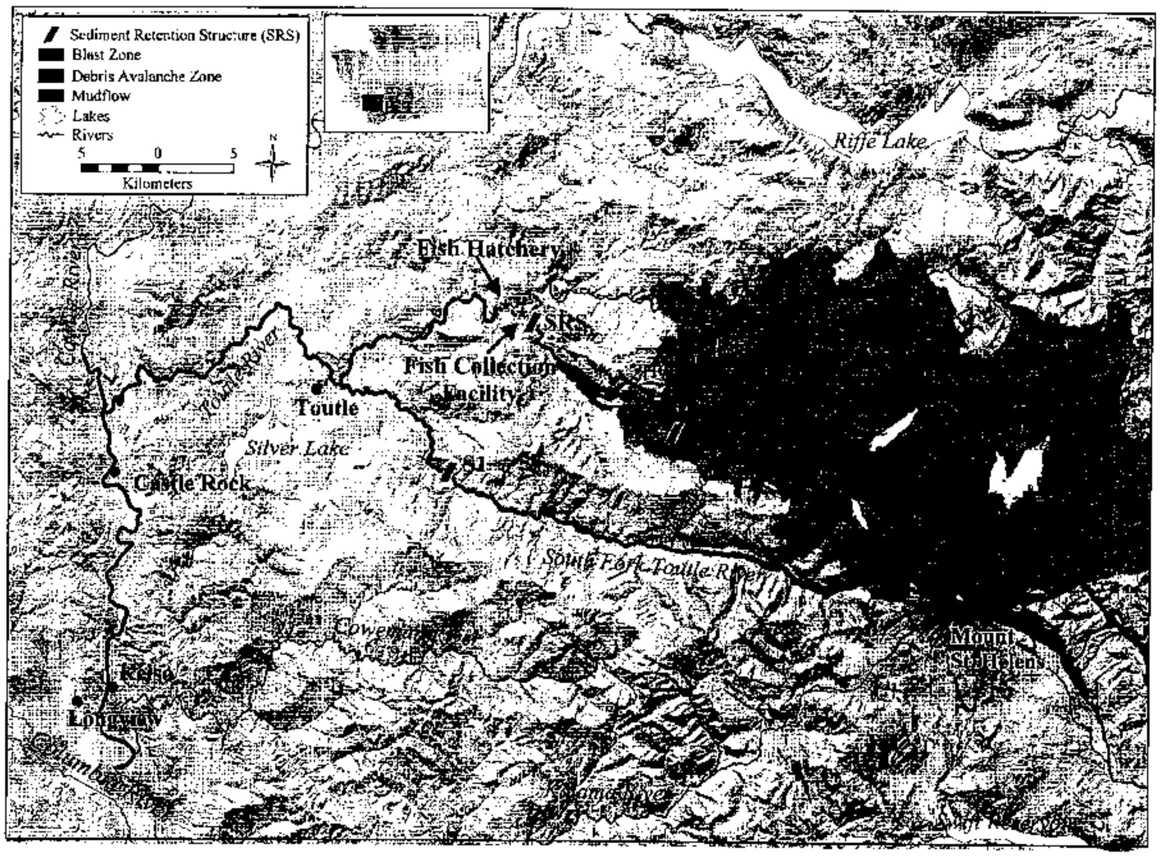
12.2 Fish in Streams and Rivers

12.2.1 Preeruption Conditions

The streams and rivers draining Mount St. Helens (Figure 12.1) were among the most productive for anadromous fish in southern Washington. They supported large commercial and recreational fisheries. Before the 1980 eruption, tens of thousands of salmon, steelhead, and sea-run cutthroat trout spawned and reared in several major tributary systems of the Columbia River below Bonneville Dam that drained the Mount St. Helens area. Chinook salmon (*Oncorhynchus tshawytscha*), coho salmon (*O. kisutch*), steelhead, and sea-run coastal (anadromous) cutthroat trout were historically the most abundant anadromous salmonids in Mount St. Helens river systems, although a few chum salmon (*O. keta*) and sockeye salmon

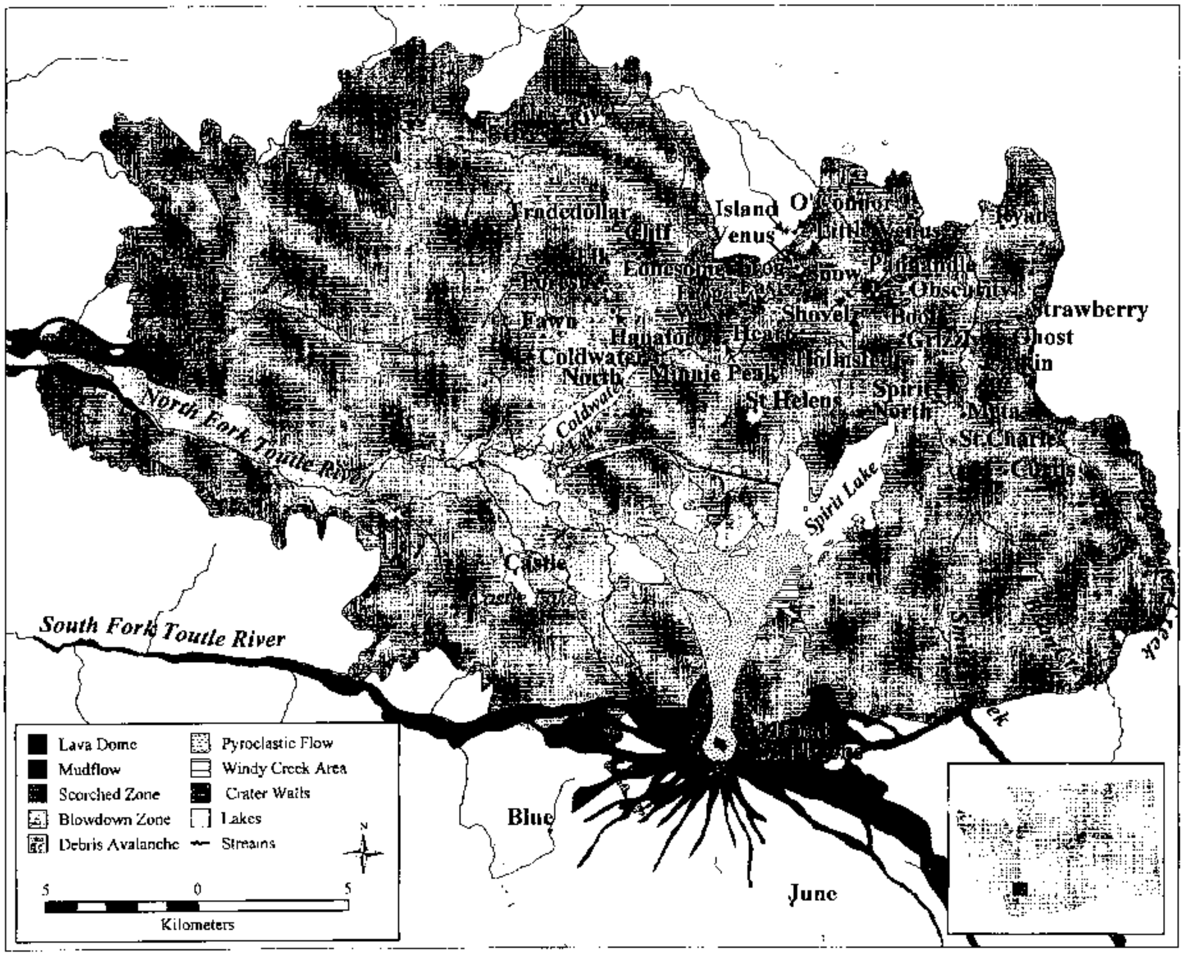
TABLE 12.1. Fish species present in the Lewis, Kalama, Toutle, and Cispus river drainages prior to the 1980 eruption of Mount St. Helens.

Family	Common name	Scientific name	Life history	Origin
Petromyzonitidae	Western brook lamprey	*Lampetra richardsoni*	Resident	Native
	Pacific lamprey	*Lampetra tridentatus*	Anadromous	Native
Salmonidae	Mountain whitefish	*Prosopium williamsoni*	Resident	Native
	Brown trout	*Salmo trutta*	Resident	Introduced
	Coastal cutthroat trout	*Oncorhynchus clarkii clarkii*	Anadromous	Native
	Westslope cutthroat trout	*Oncorhynchus clarkii lewisi*	Resident	Introduced
	Coastal rainbow trout	*Oncorhynchus mykiss irideus*	Anadromous/resident	Native
	Brook trout	*Salvelinus fontinalis*	Resident	Introduced
	Lake trout	*Salvelinus namaycush*	Resident	Introduced
	Bull trout	*Salvelinus confluentus*	Resident/anadromous	Native
	Coho salmon	*Oncorhynchus kisutch*	Anadromous	Native
	Chinook salmon	*Oncorhynchus tshawytscha*	Anadromous	Native
	Sockeye salmon	*Oncorhynchus nerka*	Resident	Introduced
Osmeridae	Eulachon	*Thaleichthys pacificus*	Anadromous	Native
Cyprinidae	Redside shiner	*Richardsonius balteatus*	Resident	Native
	Longnose dace	*Rhinichthys cataractae*	Resident	Native
	Speckled dace	*Rininchthys osculus*	Resident	Native
	Northern pikeminnow	*Ptychocheilus oregonensis*	Resident	Native
	Peamouth	*Mylocheilus caurinus*	Resident	Native
Catostomidae	Largescale sucker	*Catostomus macrocheilus*	Resident	Native
Gasterosteidae	Three-spine stickleback	*Gasterosteus aculeatus*	Resident	Native
Percopsidae	Sandroller	*Percopsis transmontana*	Resident	Native
Cottidae	Coast sculpin	*Cottus aleuticus*	Resident	Native
	Shorthead sculpin	*Cottus confusus*	Resident	Native
	Torrent sculpin	*Cottus rhotheus*	Resident	Native
	Riffle sculpin	*Cottus gulosus*	Resident	Native



a

FIGURE 12.1. (a) Location of some streams, dams, and hatcheries mentioned in the text. The streams on the flank of Mount St. Helens, including Smith Creek, are part of the Lewis River system.



b

FIGURE 12.1. (*continued*) (b) Location of lakes mentioned in the text.

(*O. nerka*), possibly strays from other Columbia River populations, were occasionally observed. Other anadromous fish used some of the rivers draining the Mount St. Helens area and included eulachon, white sturgeon (*Acipenser transmontanus*), green sturgeon (*A. medirostris*), Pacific lamprey (*Lampetra tridentatus*), and an introduced species, the American shad (*Alosa sapidissima*). Some anadromous species (Chinook salmon, coho salmon, and eulachon) have supported valuable commercial fisheries in addition to recreational fisheries; others (steelhead and sea-run cutthroat trout) have supported popular recreational fisheries (Tacoma Power and Washington Department of Fish and Wildlife 2004).

Reimers and Bond (1967) reported eight families and 29 species of freshwater fish from tributaries of the lower Columbia River in the vicinity of Mount St. Helens. The most diverse taxa were sculpins (Cottidae), which were represented by 7 of the 12 species known from the Columbia River basin, and minnows (Cyprinidae), which included redside shiners (*Richardsonius balteatus*), dace (*Rhinichthys* spp.), peamouth (*Mylocheilus caurinus*), and northern pikeminnow (*Ptychocheilus oregonensis*). Mountain whitefish (*Prosopium williamsoni*), the only whitefish species known from the Columbia River west of the Cascade Mountains, and largescale suckers (*Catostomus macrocheilus*) were widespread and abundant in many of the streams. Distribution limits of fish upstream in the drainage networks were usually bounded by waterfalls, with most species absent from reaches above large falls unless colonization occurred (1) by stream capture (i.e., diversion of a stream from one drainage network to another, often through headward erosion or damming and diversion by natural geological processes), (2) before formation of the falls, or (3) via deliberate introduction by humans.

Because the Mount St. Helens area has a long history of large natural disturbances (including eruptions by nearby Cascade Mountain volcanoes as well as several periods of glaciation within the Quaternary Period), most species have undergone episodes of local extirpation followed by recolonization (Wydoski and Whitney 2003). The lower Columbia River provided important refugia during many of these disturbances and served as a source of new colonists following local catastrophic events (McPhail and Lindsey 1986).

Three major river systems drain the slopes of Mount St. Helens: the Cowlitz River, Kalama River, and Lewis River (see Figure 12.1). Of these, only the Kalama River has remained undammed; each of the others have several flood-control and hydroelectric dams that block the migration of anadromous fish and seasonal movements of resident fish. Some salmon and steelhead adults in the Cowlitz River are captured in traps and trucked above the dams. Additionally, each of the rivers possesses several fish hatcheries that propagate both anadromous and resident salmonids. A salmon hatchery on the Kalama River is one of the oldest in the Pacific Northwest, having been in operation since the 1890s. At its completion in 1968, a hatchery on the Cowlitz River produced more salmon than any other hatchery in the world. It continues to maintain annual releases of more than 10 million Chinook and coho salmon. The hatcheries were built to mitigate for losses of habitat upon completion of dams and to provide additional fish for harvest (Lichatowich 1999).

12.2.2 Posteruption Conditions in Streams and Rivers

12.2.2.1 New Conditions Created by Eruption

The immediate impact of the May 18, 1980 eruption was catastrophic to stream-dwelling fish populations inhabiting the Toutle River, a large tributary of the Cowlitz River (see Figure 12.1). An enormous debris avalanche and numerous mudflows caused the most damaging effects. The debris avalanche buried the uppermost 25 km of the main-stem North Fork Toutle River. Mudflows occurred in the north and south forks of the Toutle River, and smaller mudflows affected the upper Kalama River and tributaries of the Lewis River (see Swanson and Major, Chapter 3, this volume). The mudflows contained exceptionally high suspended-sediment levels (greater than 10,000 mg l^{-1}), with a peak suspended-sediment concentration of 1,770,000 mg l^{-1} being recorded in the Toutle River. In addition, some mudflows contained heated water (greater than 30°C) from pyroclastic flows and from water contained in hot deposits of the main debris avalanche (Dinehart et al. 1981). Fish mortality could not be documented, but it must have been nearly complete in the parts of rivers experiencing the debris avalanche or mudflows. During the summer and early fall of 1980, suspended sediment levels in the Toutle River remained at 300 to 1000 mg l^{-1}, a range that was found to be lethal for fish exposed to Mount St. Helens mudflow and tephra particles (Stober et al. 1981). Yet, some adult steelhead returned to the river. Mudflows continued in the Toutle system in the years that followed the 1980 eruption (Swanson and Major, Chapter 3, this volume), some of which led to large changes to channel morphology.

Before the 1980 eruption, the Toutle River system contained approximately 280 km of streams used by salmon, steelhead, and sea-run coastal cutthroat trout. Volcanic mudflows and the main debris avalanche in total inundated 169 km (58% of the length of streams available to anadromous salmonids), including the entire main stem of the Toutle River. The mudflows also blocked access to some tributaries, but the number of streams and the length of potential habitat lost were not known.

In addition, all streams within a 350-km^2 area in a wide arc north of Mount St. Helens were affected by the powerful lateral blast that leveled the forest, sending trees into and across stream channels. These streams and adjacent hillsides also received varying amounts of blast material, coarse pumice, and ash. Rainstorms after the eruption mobilized hillside deposits, which continued to change channel substrates and morphology for the first few years following the eruption. Nonetheless, many fish survived and persisted during the early 1980s in tributaries of severely impacted mainstem rivers. For example, in 1981, juvenile coho salmon were present in tributaries of the Green River, and steelhead and cutthroat trout were observed at high densities in several tributaries of the south and north forks of the Toutle River. These survivors played an important role in the recolonization of streams that were severely impacted by the eruption.

Adult salmon and steelhead straying was an important survival mechanism. One or more age cohorts of the anadromous species were at sea during the 1980 eruption. The first spawning adults of these cohorts returned to their natal rivers in summer and early autumn of 1980. For the next 2 years, many adult salmon and steelhead returning to Mount St. Helens streams had been born and reared under preeruption conditions. Physical changes to the rivers and to the chemical properties of the water were so great that olfactory cues guiding adults back to their natal streams were probably disrupted, and many fish strayed from their rivers of origin. Lieder (1989) found that large numbers of adult steelhead entered relatively unaffected tributaries of the Columbia River near the most heavily impacted rivers, the Cowlitz River and Toutle River. Estimates of adult steelhead straying from volcanically impacted rivers increased from 16% preeruption to 45% posteruption. Leider (1989) believed that winter-run steelhead strays originated from both the Cowlitz and Toutle rivers while summer-run steelhead strays were primarily from the Toutle River. Small numbers of adult salmon and steelhead, however, did navigate sediment-laden waters of main-stem rivers to return to small tributaries of the Cowlitz and Toutle rivers in 1980 (Martin et al. 1984; Lucas 1985), where they presumably spawned. Somewhat surprisingly, Leider (1989) found no evidence that the temporary infusion of Cowlitz River and Toutle River steelhead strays into the neighboring Kalama and Lewis Rivers produced significant increases in adult returns to these rivers during the mid-1980s.

Elevated concentrations of volcanic sediment in the Cowlitz and Toutle rivers were believed to be the primary cause of returning salmon and steelhead adults straying to other river systems (Whitman et al. 1982). Chronically elevated suspended sediment continued to affect juvenile and adult salmon wherever they encountered it for a number of years after the 1980 eruption. Redding and Schreck (1982) exposed juvenile steelhead to relatively low (500 mg l^{-1}) and high (2000 to 3000 mg l^{-1}) levels of Mount St. Helens ash. They found evidence of sublethal stress (i.e., elevated corticosteroid and hematocrit) when exposure to either concentration was continuous for 48 hours, but fish were able to tolerate this relatively short exposure to volcanic sediment without exhibiting prolonged physiological stress responses. Redding and Schreck (1982) believed that extended exposure to abrasive sediment would erode the mucous coating on gills and cause respiratory impairment.

Elevated volcanic sediment concentrations have continued in the North Fork Toutle River below the permanent sediment-retention structure (see Figure 12.1a). Olds (2002) reported suspended-sediment levels of 252 to 1970 mg l^{-1} during the salmon smolt (juvenile seaward migrant) emigration period of March through May from 2001 to 2003. These concentrations, combined with high water velocity, were linked to reduced smolt survival in the Toutle River on the basis of sediment tolerances of salmonids in laboratory studies (Olds 2002).

12.2.2.2 Sediment-Retention Structures

After the eruption, concerns about the threat of erosion and flooding of the heavily developed lower Cowlitz River and Columbia River floodplain led to construction of several sediment-retention structures (dams) during the 1980s. Two low structures were completed within several months of the May 1980 eruption, one on the north fork and one on the south fork of the Toutle River. The structures were less than 10 m high and were meant to contain sediment eroded during the initial posteruption years. The temporary North Fork Toutle River sediment structure blocked upstream salmon and steelhead migrations, but the South Fork Toutle River structure was equipped with a fish ladder that passed adult salmon and provided a means to assess numbers of returning fish. Floods breached the structure on the North Fork Toutle River the first year, and the U.S. Army Corps of Engineers, at the request of Washington Department of Fish and Wildlife and numerous sports groups, removed the South Fork Toutle River structure 2 years later.

The very large sediment-retention structure on the North Fork Toutle River was completed by the Corps in 1989. It was placed about 1.2 km upstream of the mouth of the Green River. This structure was designed to be permanent, and upon completion it extended approximately 50 m above the streambed and 600 m across the North Fork Toutle River valley. The structure is located 48.8 km upstream from the mouth of the Toutle River and is too high to include a fish ladder; thus, it is a barrier to salmon and steelhead using the upper North Fork Toutle River watershed. The species most heavily impacted by the structure are Chinook salmon, coho salmon, steelhead, and sea-run cutthroat trout, as well as other fish moving upstream, such as minnows and suckers.

To mitigate for upriver losses, a fish-trapping facility was built about 1 km downstream of the sediment-retention structure in 1989. Upstream-migrating salmon and trout adults trapped at this facility are trucked above the dam and released into tributaries to spawn. Hatchery-origin summer steelhead that are captured in the collection facility are moved back downstream so they will not interfere with the success of the native Toutle River winter-run steelhead, which are transported upstream. Initially, sand accumulated at the trap's intake, preventing fish from entering it. The problem became acute during the mid-1990s as the pool behind the dam filled with sediment and large quantities of sand began passing over the spillway, aggrading the river near the fish-trap intake. The Corps has repeatedly improved access to the fish trap by removing sediment. The dam also caused sedimentation in the lower reaches of Alder Creek and Hoffstadt Creek when sediment-laden water pooled behind the dam deposited sand near the mouths of the two streams. This sedimentation caused severe degradation to some of the highest quality coho salmon and steelhead spawning areas that existed before the eruption.

Downstream-migrating smolts pass over the dam's spillway, a concrete channel 670 m long with an average slope of 7%. On average, 22% of the coho salmon smolts passing over the spillway received external injury from the spillway in 2001 and 2002 (Olds 2002). Impacts were found to be greater when velocities over the spillway were elevated from heavy rains and melting snow, which resulted in higher suspended-sediment levels and greater risk of external injury to the fish from striking the spillway surface or trapped wood debris.

12.2.2.3 Salmon and Steelhead Returns

Following the 1980 eruption, many fishery managers predicted that recovery of salmon and steelhead populations would take decades because riverine habitats had been so extensively damaged. Returning adults were, in fact, scarce in the first 3 years after the eruption (Lieder 1989). Many adults strayed to nearby, unimpacted Columbia River tributaries, and others were unable to successfully swim through the warm, sediment-rich Toutle and Cowlitz rivers to reach spawning streams (Whitman et al. 1982). The recreational fisheries for salmon and wild steelhead returning to the Toutle River were closed immediately after the eruption and remained so until 1987 (Lucas and Pointer 1987). However, fishing for hatchery steelhead reopened on the mainstem Toutle River in 1983.

Most salmon and steelhead returning to the Toutle River during the late 1970s and in 1980 before the eruption were hatchery-produced fish. After the eruption, what few steelhead adults returned to the South Fork Toutle River were mostly naturally spawned, suggesting that the homing fidelity of wild steelhead was greater than that of hatchery fish (Lucas 1985; Quinn et al. 1991). The two major Toutle River tributaries (South Fork Toutle River and Green River) eroded through mudflow or tephra-fall deposits and returned to preeruption streambeds within a few years. In the absence of sport harvest, adult steelhead returns rebounded much more rapidly in these rivers than many managers and biologists had predicted. Numbers of steelhead redds (egg deposition sites) observed in the main stem of the South Fork Toutle River rose from 0 in 1980 to an average of 5.7 redds km^{-1} in 1984 and further to 21.5 redds km^{-1} in 1987 (Lucas and Pointer 1987). The remarkable recovery of the wild steelhead population in the South Fork Toutle River during the mid-1980s exceeded all expectations. Since that time, returns of naturally spawning salmon and steelhead declined somewhat, as did anadromous salmonids in virtually all Columbia River tributaries until 1999 when improved ocean conditions resulted in sharply increased runs.

Salmon and steelhead have been stocked into many Mount St. Helens streams to accelerate population recovery and to provide commercial and recreational harvest opportunities in the wake of the 1980 eruption. For example, in 2001, 150,000 spring Chinook salmon fry were stocked in the Lewis River at the confluence of Crab Creek, which is upstream of the three mainstem Lewis River dams, and 140,000 Chinook salmon and 220,000 coho salmon fry were stocked into the Muddy River, a tributary of the Lewis River that extends into the mudflow and blowdown zones created by the 1980 eruption. In addition to these fish stockings, 7,000 adult coho salmon and 54 adult Chinook salmon were stocked in Swift Reservoir on the Lewis River in 2001 to enrich the reservoir and its tributaries with the nutrients from their carcasses. Emphasis on supplementing Toutle River populations with juvenile hatchery salmon ended about a decade after the 1980 eruption; however, transport of adult salmon and steelhead from the North Fork Toutle River fish trap to Hoffstadt Creek and the Green River is continuing.

12.2.2.4 Refugia for Resident Fish

Colonization of streams containing resident (nonanadromous) fish after the 1980 eruption was strongly influenced by the presence of several different types of refugia. Headwater streams typically had waterfalls and other natural barriers that prevented fish from entering them from downstream. Other streams possessed anthropogenic barriers, such as dams and impassable culverts at road crossings, which likewise limited upstream movement. If fish survived the eruption in refugia, these barriers could have important implications for the repopulation of fish in disturbed drainages. Hawkins and Sedell (1990) examined the dispersal of aquatic flora and fauna into Mount St. Helens streams based on a long-term monitoring study of the Clearwater Creek drainage, a tributary of the Lewis River within the blowdown and tephra-fall zones. For brook trout (*Salvelinus fontinalis*) and cutthroat trout, the primary refuge sites were headwater lakes that were covered by ice and snow at the time of the eruption (Hawkins and Sedell 1990; Crisafulli and Hawkins 1998). Resident cutthroat trout may also have survived in the upper reaches of tributaries that were impacted only by tephra fall. Once suitable habitat was present, these fish or their progeny colonized downstream portions of the drainage network from which fish had been extirpated during the eruption. Sculpins appeared to have survived within tephra-fall streams and rebounded to relatively high abundance during the 1980s in response to favorable habitat (shallow, sandy reaches with dense algae and large midge populations). Within 3 years of the eruption, sculpins recolonized the main stem of Clearwater Creek, either from headwater tributaries impacted by tephra fall or springs located in the floodplain of the stream (Crisafulli and Hawkins 1998).

Efforts to reestablish steelhead may have resulted in the establishment of resident rainbow trout populations (steelhead are the anadromous form of rainbow trout). In the west fork of Schultz Creek, a Green River tributary, hatchery steelhead were stocked in the 1980s above a barrier falls and have since established a nonmigratory local breeding population. Our data show that these rainbow trout may have hybridized with native cutthroat trout, because trout with intermediate morphological features began to appear in the late 1980s. The frequency of putative rainbow and rainbow–cutthroat trout hybrids gradually increased through the 1990s, and by 2003, no visually distinct cutthroat trout were observed in this stream, suggesting that introduced rainbow trout had completely displaced the native cutthroat trout population. A stream draining Venus Lake (see Figure 12.1) also supported rainbow and cutthroat trout (and apparently their hybrids). These species were observed during electrofishing surveys conducted in 1994, 14 years after the eruption. These fish likely originated from fish stocked in Venus Lake because natural barriers prevented dispersal upstream into Venus Lake from the Green River.

In our electrofishing surveys of 19 second- and third-order streams within the Muddy River and Green River systems of the blowdown zone during 1994 and 1995, cutthroat trout were found in 6, brook trout in 4, rainbow trout in 1, and sculpins in 6 streams. Most of the streams were connected to lakes where fish were known to have survived the eruption. Even if the stream populations were extirpated, headwater lakes may have served as source populations for recolonization. Sculpins, capable of seeking refuge in interstitial spaces within the substrate (Bond 1963), were assumed to have survived in the stream network, particularly in systems with tributaries extending into the less-disturbed tephra-fall zone.

Resident fish in the blowdown zone relied on at least two forms of refugia: ice-covered lakes and connected tributaries that flowed through the less-impacted tephra-fall zone. The distribution of these refugia influenced the initial patterns of survival and subsequent recolonization events. The importance of refugia for resident fish appeared to have varied by species. Lakes served as important refugia for some species, whereas in-stream cover and microhabitats facilitated the survival of other stream fish.

12.2.2.5 Stream Habitat Development

Streams affected by the 1980 eruption experienced a variety of impacts and developed habitat conditions suitable for fish colonization or population growth at different rates during the next 25 years. Headwater streams in the blowdown zone received 30-cm to more than 100-cm tephra deposits. Their riparian zones and valley-wall forests were leveled by the lateral blast, leaving stream channels open to warming via direct solar radiation. During subsequent autumn and winter freshets, these streams carried very high levels of suspended sediment, and they received even more sediment from erosion of hill slopes, including landslides. Debris flows were common in some portions of the blowdown zone during the first few years after the 1980 eruption and again in 1996, resulting in many small streams having log jams at or near their mouths. The large jams may have inhibited salmon and trout from entering some Toutle River system tributaries.

Mudflows along the North Fork Toutle River and South Fork Toutle River (the Green River did not experience mudflows) created elevated sediment terraces that blocked confluences of the small streams flowing into them. Many tributaries created entirely new channels as they cut across these mudflow terraces before entering the main-stem stream (Figure 12.2). The new channels were almost completely devoid of riparian vegetation in the first year after the eruption. Their streambeds contained very little large wood and other potential habitat structures. Mudflow terrace reaches of tributary streams ranged in length from less than 100 m to several kilometers, and they were gradually colonized by aquatic invertebrates and fish from both the headwater streams and the rivers into which they flowed. Because these reaches were essentially new channels, they presented an extraordinary opportunity for studying early-successional patterns in low-gradient stream ecological systems.

Martin et al. (1982, 1986) studied nine streams in volcanically disturbed and undisturbed drainages near Mount St. Helens in 1981 and 1982. They found that juvenile coho salmon survived poorly in the volcanically disturbed streams in summer because they experienced lethal and highly variable water temperatures. They also found that apparent winter survival (i.e., accounting for actual death plus emigration) of juvenile coho salmon was low in volcanically disturbed streams, which they attributed to lack of in-channel habitat complexity and hiding cover. It is possible that survival of these largely hatchery-bred fish was lower than survival of naturally spawned coho (Nickelson et al. 1986) or that they responded differently to the altered habitat. Nevertheless, Martin et al. (1986) concluded that two factors would improve the recovery of fish habitat in Mount St. Helens streams: (1) reestablishment of riparian vegetation, which would moderate stream temperatures, and (2) recruitment of large woody debris, which would provide

FIGURE 12.2. South Fork Toutle River in the Herrington Flats area in 1981. Photo *inset* shows the lower section of Herrington Creek, where the stream cut a new channel through the mudflow terrace. (Photo credits: P.A. Bisson.)

physical cover in winter. They estimated that 5 to 20 years would be needed for riparian vegetation to provide effective shading for productive fish habitat and that 50 to 75 years would be required for new wood to be recruited from riparian forests.

Bisson et al. (1988) studied coho salmon recovery in three Toutle River streams from 1983 to 1986, including one of the streams used by Martin et al. (1986) in their investigation from 1981 to 1982. Coho salmon stocked in the three study sites (one site in a mudflow terrace stream and two sites in blowdown-zone streams) exhibited increasing summer production during this period despite poor physical habitat (less than 30% of the stream area in pools) and high temperatures. By 1986, juvenile coho salmon production, expressed in milligrams of new tissue produced per square meter per day, was found to be twice as great as production rates of juvenile coho salmon stocked in nearby old-growth forested streams (Bilby and Bisson 1987). At the Mount St. Helens sites, these values ranged from 2.3 to 21.6 g m^{-2} over a 150-day warm-season period. The remarkably high productivity occurred during a period when summer temperatures in one of the streams reached 29.5°C, several degrees above the assumed lethal threshold for salmonids (Bjornn and Reiser 1991). Bisson et al. (1988) attributed this extraordinary productivity to an abundance of both aquatic and terrestrial food resources, caused in part by increased light levels and associated increases in net primary productivity and by a relative absence of predators and competitors.

Peak temperatures in Herrington and Hoffstadt creeks (Figure 12.3) frequently exceeded the 24°C assumed lethal threshold for salmonids during the 1980s, but episodes of these lethally high temperatures declined during the 1990s. In spite of potentially hazardous thermal conditions during the first 22 years after the eruption, all three streams continued to support salmon and trout, and one stream supported sculpins. Fish may have survived high temperatures by making temporary use of cool groundwater seeps and other thermal refugia (Bilby 1984), where these features were available. However, more research is needed on the actual mechanisms of survival in a thermally hostile environment.

Recovery of stream habitat and fish populations was followed in the three streams studied by Bisson et al. (1988) from the early 1980s to 2002. Maximum summer water temperature (see Figure 12.3) gradually declined at both the mudflow terrace stream (Herrington Creek) and the two blowdown-zone streams (Schultz Creek and Hoffstadt Creek). Peak temperature declines were related to recovery of riparian vegetation, particularly red alder (*Alnus rubra*), that formed dense riparian stands and shaded the stream channels (Figure 12.4). Riparian vegetation recovery appeared to be influenced by the proximity of seed sources. The riparian zone adjacent to Herrington Creek was rapidly colonized by alder; a nearby intact upland alder stand likely served as a seed source.

From 1983 to 2002, the relative abundance of pool habitat [the other factor believed by Martin et al. (1986) to potentially limit fish recovery in Mount St. Helens streams] has been measured annually by computing the surface area of pools relative to other habitat types. The percentage of pools (Figure 12.5) increased in both Herrington and Schultz creeks but not in Hoffstadt Creek. The rapid rise in pool habitat in Herrington Creek from 1981 to 1983 resulted from exposure of large boulders by channel incision through mudflow deposits. The subsequent increase in pools to 70% of the stream area from 1987 to 1989 was caused by beaver (*Castor canadensis*) activity. When the beavers abandoned lower Herrington Creek in 1990, the beaver dams were breached by high flows in winter storms, and the percent of the wetted channel composed of pools declined to about 50%. The increase in pools in Schultz Creek was related to the recruitment of boulders and wood during winter floods. In Hoffstadt Creek, which was scoured nearly to bedrock by posteruption debris flows, pool area has remained an almost constant 35% through 2002. The relative scarcity of pools in Hoffstadt Creek might favor riffle- and cascade-dwelling fish, such as sculpins and longnose dace (*Rhinichthys cataractae*), but such species had not yet successfully colonized this stream by 2002. In spite of the lack of pool habitat in Hoffstadt Creek, juvenile steelhead and coho stocked in the 1980s survived and grew at rates equal to or greater than those in relatively undisturbed streams in the region. Progeny of

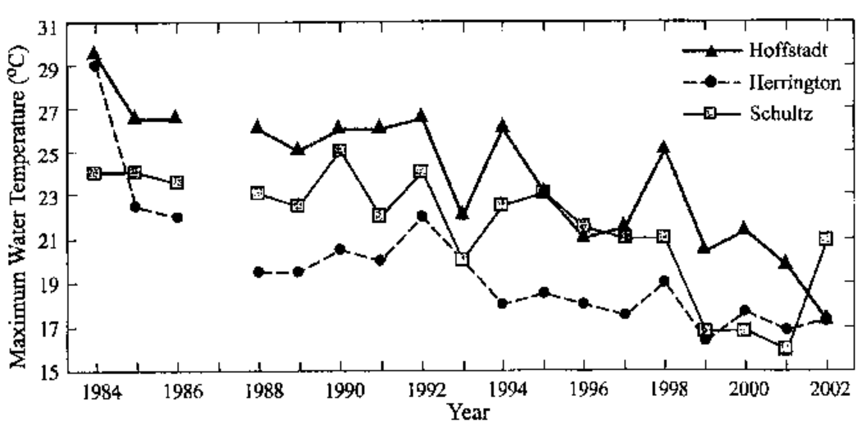


FIGURE 12.3. Maximum summer water temperatures measured in three tributary streams of the Toutle River from the early 1980s to 1999. Herrington Creek is a mudflow terrace stream (see Figure 18.3); Schultz Creek and Hoffstadt Creek are blast-zone streams. Missing years are denoted by *broken lines*. [Based on Martin et al. (1986), Bisson et al. (1988), and thermograph data collected from 1989 to 1999.]

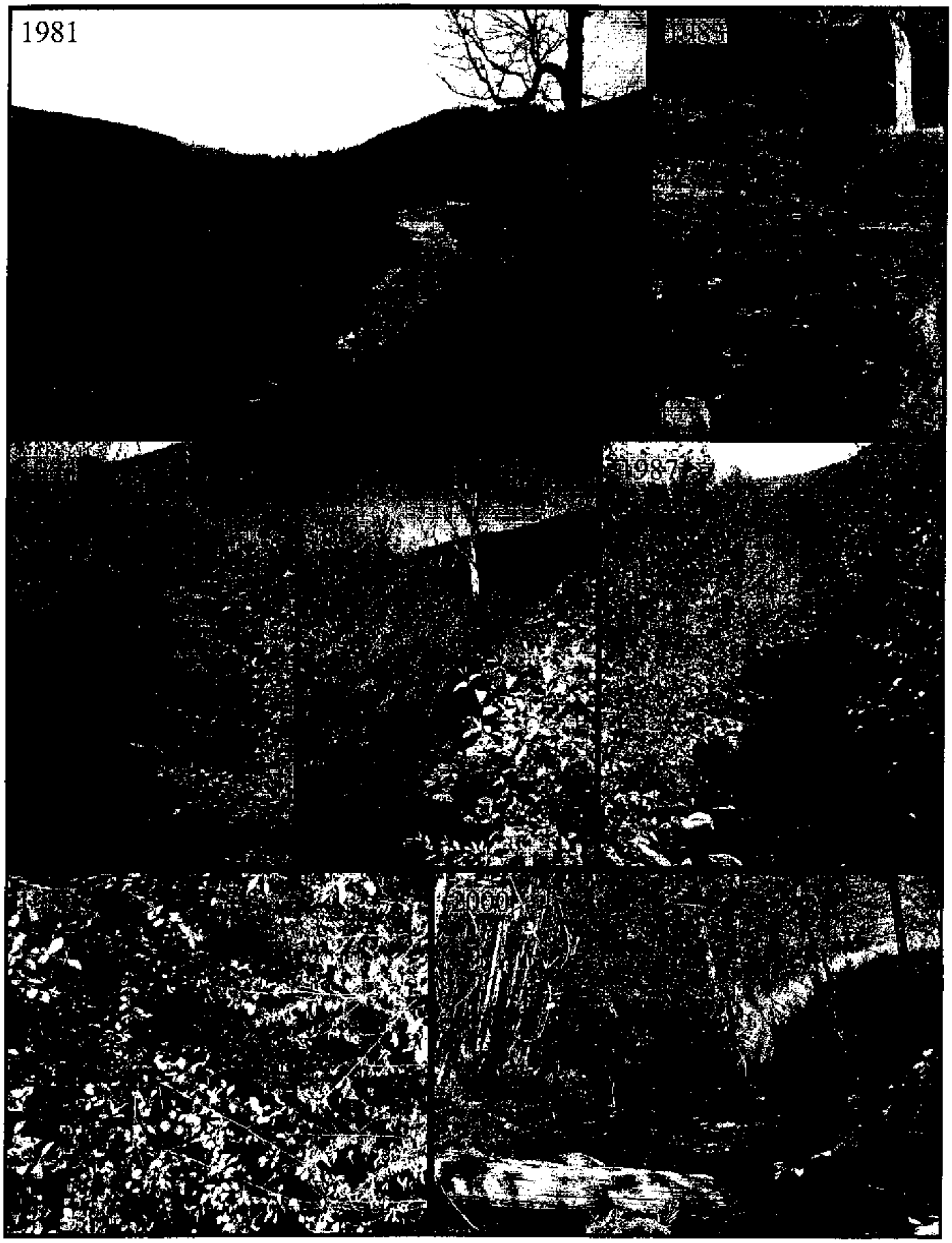


FIGURE 12.4. Chronosequence of photographs taken from approximately the same location on lower Herrington Creek, a mudflow terrace tributary of the South Fork Toutle River. (Photo credits: P.A. Bisson and B.R. Fransen.)

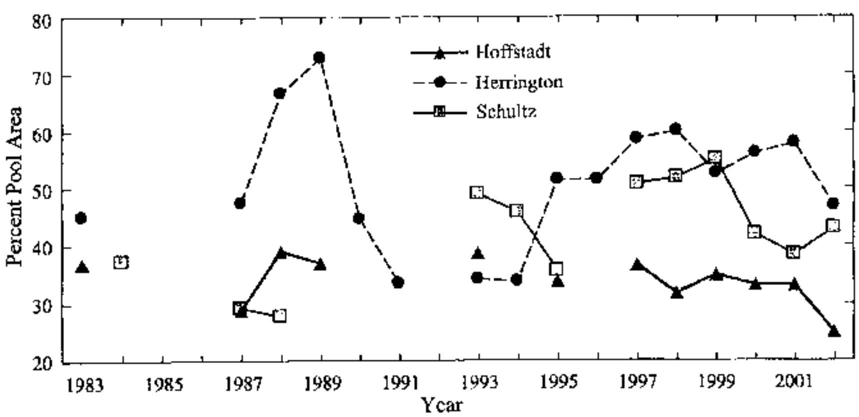


FIGURE 12.5. Trends in the percentage of pool habitat in three Mount St. Helens streams. Percentages are based on the fraction of the wetted channel occupied by pools during summer flow conditions. [Based on Martin et al. (1986), Bisson et al. (1988), and midsummer field surveys from 1989 to 1999.]

adult steelhead transported to Hoffstadt Creek have also survived well. In the upper reaches of the stream, cutthroat trout persisted in the absence of competing steelhead.

Excluding the first 2 posteruption years, the biomass of salmonids (Figure 12.6) has been both variable and high relative to many streams in the region. Cascade Mountain Range streams tend to be cold, oligotrophic ecological systems with total salmon and trout biomass typically ranging from 1 to 4 g m^{-2} (Bilby and Bisson 1987). In Herrington, Hoffstadt, and Schultz creeks, salmonid biomass has rarely dipped below 2 g m^{-2} and has occasionally exceeded 10 g m^{-2} between 1983 and 2002. In Herrington Creek, highly variable summer fish biomass during the 1980s resulted from differences in the timing and numbers of stocked coho salmon, but after hatchery releases were discontinued, the total biomass was relatively stable. Schultz Creek, one of the blowdown-zone streams, exhibited a peak in total salmonid biomass in the mid-1980s when coho salmon were stocked in it, but a second increase in biomass resulted instead from naturally spawning cutthroat and rainbow trout. In Hoffstadt Creek, relatively high biomass in the 1980s resulted, in part, from hatchery coho salmon stocking and in the 1990s from steelhead stocking. All three streams have received fish of hatchery origin, and those fish have been able to survive and grow in hostile conditions. The high growth rates suggest that the streams are relatively food rich, although we do not know with certainty whether the food resources are primarily of aquatic or terrestrial origin. Additionally, it is possible that the hatchery fish possessed some characteristics (such as tolerance for high densities or higher growth rates) that were well adapted to the posteruption environment.

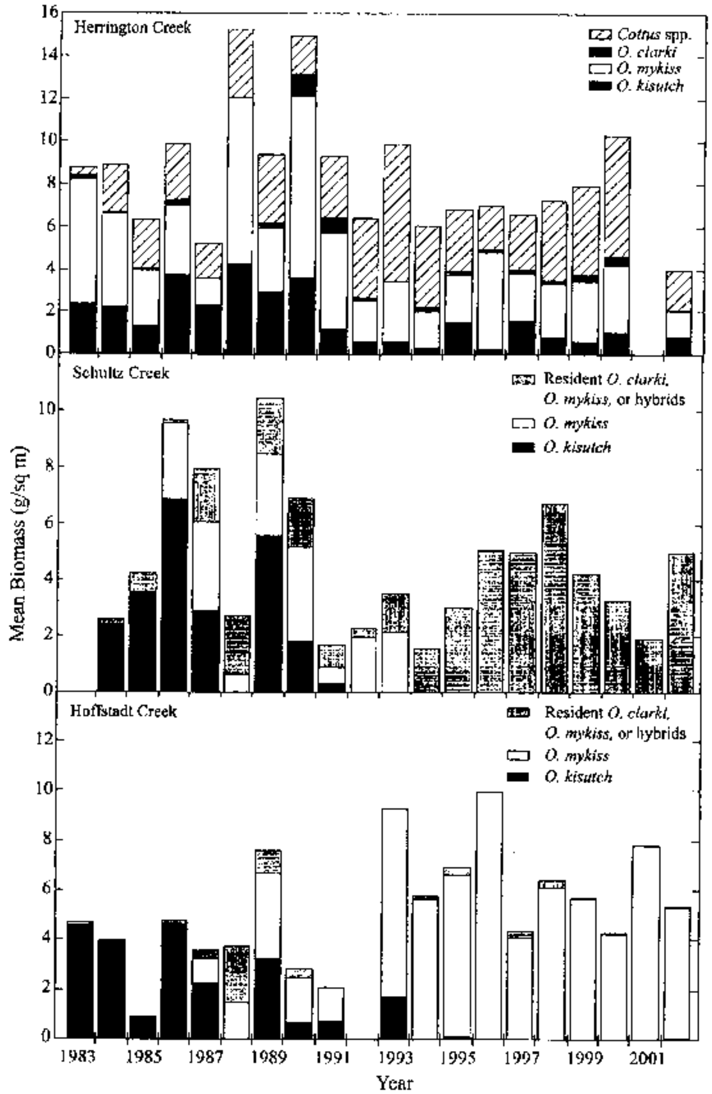
Partial support for the speculated importance of food for fish survival and production was provided by a study of the physical and biological factors influencing the abundance of trout in Clearwater Creek (see Figure 12.1a; Baker 1989). Baker observed a significant positive association between cutthroat trout density and drifting invertebrates, although the association between brook trout abundance and estimated food availability was not statistically significant. Baker also found that pool quality (measured by size and presence of cover) was more important than simply the number of pools. Large, deep pools held proportionally more adult trout than did small pools. In terms of overall trout abundance, food availability slightly outweighed physical factors, such as substrate size and pool size, in influencing the abundance of trout in pool habitats. This finding was consistent with other monitoring studies of salmonid populations near Mount St. Helens (Bisson et al. 1988) and suggests that posteruption conditions favored an abundance of terrestrial and aquatic food organisms.

12.2.2.6 Long-Term Fish Productivity in Streams

Many fish populations at Mount St. Helens recovered more quickly than originally thought possible after the 1980 eruption. On the basis of the overall results of different monitoring studies, a generalized disturbance and recovery figure (Figure 12.7) illustrates some of the important processes and factors underlying the initial crash and subsequent rebound of fish in streams impacted by the eruption. These processes, described next, seem to have occurred regardless of the type of volcanic disturbance; that is, response patterns in debris-avalanche, mudflow, and blowdown-zone streams were similar.

The causes of initial declines were obvious. Many fish were killed outright during the May 18 eruption and associated mudflows by physical forces (i.e., abrasion and heat). Extreme posteruption sediment and temperature levels far surpassed tolerance thresholds for the cold-water fish species inhabiting streams near Mount St. Helens. Of long-term concern was the loss of cover, previously provided by large logs, in streams experiencing posteruption debris flows. However, many streams in the blowdown zone actually accumulated wood as the result of widespread forest blowdown. Within 3 years, fish population recovery was under way in many areas. Juvenile anadromous and resident fish surviving in the less-impacted tephra-fall and blowdown-zone streams were important sources of colonists throughout many of the drainage networks. The presence of these survivors, coupled with their dispersal ability and the connectivity of aquatic systems, led to a surprisingly rapid

FIGURE 12.6. Total biomass of salmonid fishes (*Oncorhynchus kisutch*, *O. mykiss*, and *O. clarki*) in three Mount St. Helens streams. [Based on Martin et al. (1986), Bisson et al. (1988), and summer electrofishing surveys from 1989 to 1999.]



recovery of some populations. In addition, cohorts of salmon and steelhead that were at sea during the eruption returned to spawn; although many returnees initially strayed to nearby unimpacted rivers, some returned to their natal streams and refounded wild populations.

Fishery managers also played a hand in rebuilding some populations during the 1980s by imposing a temporary moratorium on sport harvest. This management decision coincided with rapid increases in both the number of successfully returning adults and total juveniles rearing in streams having anadromous species. The role that aggressive stocking programs played, using both native fish and stocks from other river basins, in salmonid recovery is less clear but probably did increase the number of returning fish. However, the planting of nonnative salmon in waters that still had surviving native stocks may have resulted in changes in the genetic composition and fitness of naturally spawning populations (Independent Scientific Advisory Board 2003).

The rapid posteruption rebound was also driven by a variety of ecological processes. In many channels, fine sediment from the eruption was flushed during high flows so that original gravel-cobble streambeds were recovered within 1 to 3 years. Dense riparian plant communities, including herbs and shrubs [salmonberry (*Rubus spectabilis*), buttercup (*Ranunculus* sp.), coltsfoot (*Petasites frigidus*), fireweed (*Chamerion angustifolium*), and pearly everlasting (*Anaphalis margaritacea*)] as well as vigorously growing deciduous trees (red alder and willow), began to provide shade and moderate stream temperature, reduce erosion, and provide habitat for terrestrial invertebrates specialized for living on herbaceous vegetation. However, many streams continued to receive abundant sunlight during the first 10 years following disturbance. The high solar

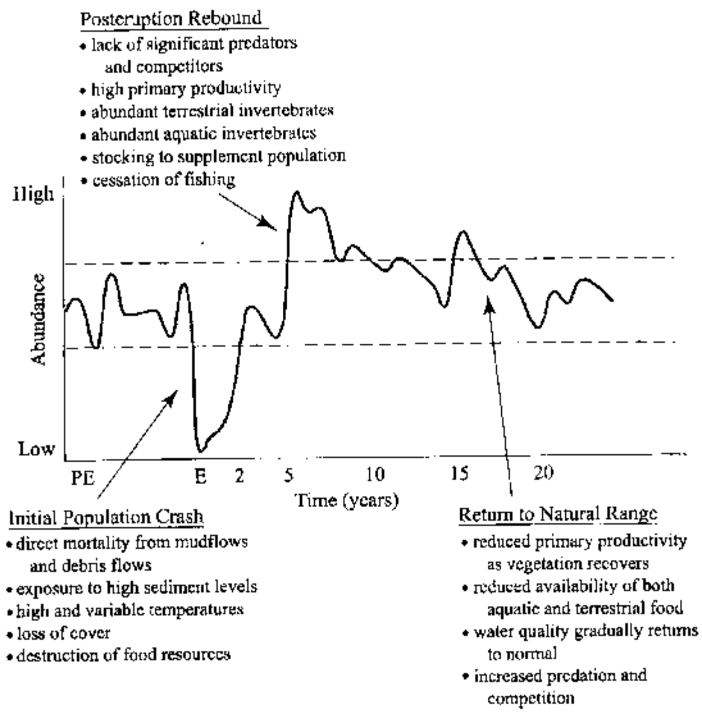


FIGURE 12.7. Hypothetical causes of posteruption fish-population crash, subsequent rebound, and gradual return to the range of abundance (bounded by *dashed lines*) typical of streams in the western Cascade Mountains. Time is shown for pre-eruptive conditions (PE), during the eruption (E), and in the years following the 1980 eruption.

radiation levels provided energy for elevated primary production by green algae and diatoms, which in turn enhanced grazer and collector-gatherer aquatic invertebrates, such as baetid mayflies (Baetidae) and orthocladiid midges (Chironomidae), which are common prey of juvenile salmonids (Mundie 1974). In general, fish tended to recolonize streams, often with human assistance, more rapidly than did potential aquatic competitors and predators (e.g., crayfish and amphibians), which were not restocked in streams where they had been extirpated. As early-successional top carnivores, fish were likely able to take advantage of temporarily abundant food.

The second posteruption decade was marked by a gradual return of stream-dwelling fish to abundances more typical of the western Cascade Mountains (see Figure 12.7). In some streams, pool habitat was scarce and may remain so until large trees grow and fall into the channel, a multidecadal process. However, summer water temperatures continued to decline as riparian trees provided more shade, and primary productivity presumably returned to levels typical of forested streams in southwestern Washington, with a corresponding reduction in mayflies and midges. The development of tree-dominated riparian zones has also reduced the amount of herbaceous vegetation, which may have lowered the number of terrestrial invertebrates falling into streams from herbs and shrubs. Over time, it is likely that a more complete assemblage of top aquatic carnivores will return to Mount St. Helens streams, leading to more competition and predation.

The pattern of initial fish response to the eruption and subsequent rebound observed in Mount St. Helens streams (see Figure 12.7) has been observed in fish exposed to other severe disturbance events, such as floods and wildfires (Minshall et al. 1989; Spencer et al. 2003). Waters (1983) found that a flood accompanied by a debris flow in a Minnesota stream caused a sharp drop in the abundance of fish, but after several years there was a rapid increase in trout populations as the stream habitat recovered. Minshall et al. (1989) and Spencer et al. (2003) documented significant changes in the food webs of streams impacted by large wildfires in the northern Rocky Mountains. They found that reduction of the forest canopy facilitated a shift in favor of productive autotrophic food webs (those based on algal production within the streams) and away from heterotrophic food webs (those based on terrestrial leaf litter and other allochthonous food sources). Minshall (2003) noted that, after fire, streams tended to converge on prefire conditions within 10 to 15 years. These case studies suggest that the pattern of decline and rebound observed at Mount St. Helens streams is consistent with disturbance-recovery patterns documented elsewhere.

Literature on fish responses to volcanism is relatively scant, but there are at least two examples from the North Pacific. Eicher and Rounsefell (1957) studied the effects of tephra deposits on sockeye salmon following the 1912 eruption of Mount Katmai, Alaska. Four thousand adult salmon died during the eruption because of suffocation in a sediment-choked stream that received 25 cm of tephra fall. Several months after the eruption, streams still contained abundant sediment, which was believed to have caused the death of several hundred additional sockeye salmon and the nearly complete loss of their food base. Two years after the eruption, intense storms added more sediment to the streams. Fewer than average salmon returned to spawn 4 to 8 years after the eruption, supporting the idea that the event had depressed the populations for at least a few generations. However, after this period, the salmon populations rebounded to preeruption levels. Eicher and Rounsefell (1957) suggested that, following an initial depression in productivity, the tephra fall may have promoted sockeye growth because smolt sizes from the volcanically impacted systems were substantially larger than those from adjacent undisturbed sites.

The second example is from the 1955 eruption of Mt. Besymjanny, Kamchatka, Russia, where Kurenkov (1966) reported a decline in the number of adult sockeye salmon returning to Lake Asabatchye beginning 4 years after the eruption. Adult returns remained depressed until 1964, the last year reported. The duration and amplitude of the population crash and subsequent responses were influenced by the extent and severity of the disturbance, and apparently the recovery of the lake system had not progressed enough to support a normal abundance of sockeye 10 years after the eruption.

Management actions can profoundly influence recovery of native fish assemblages in postdisturbance stream environments, and there is strong evidence that management caused some changes at Mount St. Helens that may be irreversible and undesirable in terms of sustaining native species and stocks. Minshall (2003) showed that altering riparian plant communities after large disturbances (e.g., by salvage logging) changed the food web of streams. The salvage logging after the Mount St. Helens eruption was one of the largest such efforts in history and removed many downed trees from streams and adjacent riparian areas. Waters (1983) found that an introduced species [brown trout (*Salmo trutta*)] displaced a native species (brook trout) when it was stocked in a flood-disturbed Minnesota stream. Given the widespread history of salmon, steelhead, and trout stocking, as well as nonnative fish stocking in low-elevation lakes near Mount St. Helens, long-term changes in fish communities resulting from fisheries management are a likely possibility. As a consequence, alteration of river and riparian recovery processes by forest management and sediment-control structures, combined with deliberate stocking of nonnative species, suggest that some streams and rivers near Mount St. Helens have been changed substantially and will likely remain so for several decades or longer.

Despite these concerns, one of the most surprising findings of research on streams and rivers at Mount St. Helens is the speed with which many have returned to near-preeruption conditions. Most experts held a pessimistic view of the prognosis for long-term recovery immediately after the eruption because changes in streams were so extreme. Twenty-two years after the eruption, many stream habitats and fish communities had returned to levels commensurate with the range of conditions found in Southwest Washington streams not affected by the volcano. Recovery has occurred more quickly than originally thought possible. Studies of stream-dwelling salmon and trout populations at Mount St. Helens have suggested that these fish may thrive in postdisturbance environments where food is abundant and predators and competitors are largely absent, even where habitats are distinctly suboptimal. The situation in lakes, however, has been different.

12.3 Lake-Dwelling Fish

12.3.1 Historical and Preeruption Conditions

Most of the 33 lakes (see Figure 12.1) that were studied in the vicinity of Mount St. Helens after the 1980 eruption were barren of fish before the arrival of Euro-American settlers (Crawford 1986). Waterfalls or other barriers on outlet streams prevented fish colonization from downstream sources. The only exception was Spirit Lake, which was connected to the Toutle River without barriers to dispersal, enabling access of sea-run coastal cutthroat trout, winter steelhead, and Coho Salmon to the lake. With the arrival of white settlers in the mid-1800s, the Mount St. Helens area was used for logging, mining, hunting, and exploration. With these activities, came the desire to provide recreational fishing in the backcountry lakes. The first recorded official fish stocking occurred in Spirit Lake in 1913, and most of the lakes were stocked by the 1950s. Few, if any, spawning surveys attempted to quantify the reproductive success of trout stocked in the lakes following either single or multiple stocking.

From 1913 through 1979, the year before the eruption, at least 1.8 million fish comprising four species and one subspecies had been stocked in the 24 lakes capable of supporting fish (Lucas and Weinheimer 2003). This preeruption stocking estimate should be viewed as the minimum number of fish stocked because it is based entirely on Washington Department of Fish and Wildlife records, which include stocking done by counties, sportsman groups, and individuals but do not include illegal or other stocking. Although the remaining 9 lakes were likely stocked, they could not support fish because of their shallow depths, producing high summer temperature and anoxia under the ice in winter.

The species stocked in Mount St. Helens lakes were brook trout, rainbow trout, westslope cutthroat trout (*O. clarki lewisi*), coastal cutthroat trout, and lake trout (*S. namaycush*). Brook, rainbow, and westslope cutthroat trout were commonly stocked in the lakes, whereas coastal cutthroat and lake trout were confined to 1 or 2 lakes and were seldom stocked. Following initial stocking, brook trout, which is a species capable of successfully spawning in lake-bottom substrates, maintained reproducing populations in the 14 lakes where they had been released. In contrast, rainbow and cutthroat trout require streams for spawning, and access to these habitats was very limited because of the presence of waterfalls on inlet and outlet streams. Consequently, reproductive success was limited, and several lakes required regular stocking to maintain their fisheries.

Lakes at Mount St. Helens were created through past volcanic eruptions, landslides, and glaciation and varied considerably in area, depth, elevation, and exposure to sunlight. As is typical of temperate montane lakes, these lakes had a fall and spring overturn period of vertical circulation and a summer thermal stratification. Lakes were ice covered for 3 to 8 months, depending on elevation. Information on the physical, chemical, and biological conditions of many of the lakes before the 1980 eruption is scant. Crawford (1986) reports very low densities of plankton from 1979 sampling of Spirit Lake. Several lakes studied by Bortleson et al. (1976) possessed low concentrations of nutrients for phytoplankton growth (phosphorus and nitrogen), high oxygen levels in the epilimnion, and water with high clarity (Secchi-depth measurements of 7 to 14 m). Mount St. Helens lakes were oligotrophic because of low nutrient levels, low phytoplankton, high light transmission, and cool temperature (Swanson et al., Chapter 2, this volume; Dahm et al., Chapter 18, this volume). Accordingly, the lakes supported relatively small standing crops of fish, and populations were often composed of stunted individuals (Crawford 1986). These fish likely foraged on the low densities of aquatic and terrestrial invertebrates typical of oligotrophic montane lakes in Washington State. Such prey consisted primarily of calanoid copepods, chironmid midge larvae and pupae, a variety of terrestrial insects, and freshwater amphipods (*Gammarus* spp.) (Crawford 1986). More than 50 years of stocking in most of these formerly fishless waters undoubtedly altered the structure of indigenous biotic communities (e.g., plankton, macroinvertebrates, and amphibians), and most lakes were no longer pristine (Knapp et al. 2001).

12.3.2 Posteruption Condition

Lakes in the Mount St. Helens landscape were disturbed by a complex set of physical mechanisms (heat, scour, and deposition) during the 1980 eruption (Swanson and Major, Chapter 3, this volume). The types, intensity, and severity of lake disturbances were related to distance and direction from the volcano and also to specific conditions at each lake at the time of the eruption (Dahm et al., Chapter 18, this volume). The immediate posteruption response of fish varied according to this array of volcanic disturbances and ranged from lakes with high survival to others with complete mortality (Crawford 1986).

Mount St. Helens lakes can be assigned to four categories based on the type of volcanic disturbance they received during the 1980 eruption. Four lakes (Blue, Island, June, and O'Connor) received only tephra fall; 28 lakes were influenced by blowdown or scorch disturbance (hereafter, blowdown); and Spirit Lake was influenced by multiple volcanic disturbances (debris avalanche, lateral blast, pyroclastic flows, and tephra fall). In addition to the 33 lakes present before the eruption, 2 large new lakes developed when debris-avalanche deposits blocked tributaries to the Toutle River, creating Coldwater and Castle lakes. For each of the lake categories, we describe species survival, subsequent natural and human-mediated (i.e., stocking) colonization, species persistence, and reproductive status of fish in these lakes from 1980 to 2002. Species are considered to have survived if they were observed in a lake within the first 5 years after the eruption and if that lake had not been stocked since the eruption (Crawford 1986).

12.3.2.1 Tephra-Fall Lakes

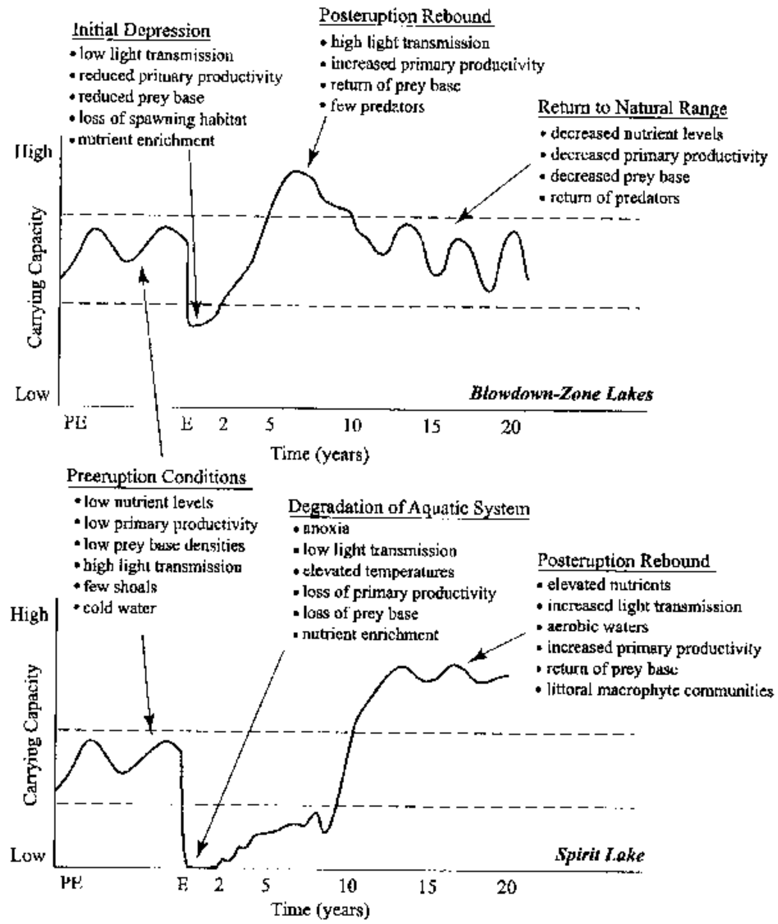
Blue, Island, June, and O'Connor lakes were stocked before the eruption, and each had fish populations that survived deposition of 5 to 15 cm of tephra. Additionally, three of the lakes maintained self-perpetuating populations of trout for 20 years posteruption in the absence of stocking. Several factors contributed to their success. At the time of the eruption, at least three, and perhaps all four, of the lakes were covered by snow and ice. Tephra entered them slowly during the spring as their ice cover melted. This slow process may have minimized the impacts of tephra on water quality and the biota. Wissmar et al. (1982b) reported that the chemical and physical properties of tephra-fall lakes were typical of undisturbed lakes of the region when measured on June 30, 1980, about 6 weeks after the eruption. The tephra that entered the water column settled out within a few weeks. Rapid settling of tephra suggests that phytoplankton were not severely impacted and that phytoplankton were sufficient to support zooplankton, an important trout food resource. However, some of the tephra was highly buoyant pumice that floated on the surface and was blown to the shoreline or became waterlogged and sank. The tephra and pumice that sank presumably covered benthic invertebrates, but the extent to which this affected trout food availability is not known. The survival and successful reproduction of fish in these lakes indicate low to moderate amounts (5 to 15 cm) of tephra fall had little or only a transient effect on the water quality, invertebrate abundance, and spawning habitat for trout. In the late 1990s, large hatches of caddisflies (Trichoptera) and mayflies (Ephemeroptera) were observed emerging from the lakes; thus, aquatic insects had become potential food resources for fish populations during the second posteruption decade.

12.3.2.2 Blowdown-Zone Lakes

Fish surveys with gill nets and angling were conducted in 28 lakes in the blowdown zone. Fish were assumed present in 19 of these lakes at the time of the 1980 eruption on the basis of stocking records for September 1979, preeruption creel censuses, and fish surviving the eruption (Crawford 1986). The remaining 9 lakes were thought to have been too shallow to support fish, lacked any stocking records, and had no other records that would have confirmed fish presence. Fish survived in 13 of the 19 lakes assumed to support fish before the eruption. The number of lakes occupied by the various trout species decreased following the eruption. Brook trout survived in 8 of 13 blowdown-zone lakes, rainbow trout survived in 1 of 5, westslope cutthroat trout survived in 3 of 18, resident coastal cutthroat trout survived in 1 of 1, and lake trout survived in 1 of 1 where they had existed previously.

Several factors contributed to fish survival and persistence in the blowdown-zone lakes, which were more heavily impacted

FIGURE 12.8. Hypothetical causes of fish-population changes in blowdown-zone lakes (*upper*) and in Spirit Lake (*lower*) for preeruptive conditions (PE), conditions during the eruption (E), and years after the 1980 eruption.



than the tephra-fall lakes. Of primary importance was the eruption's timing. Ice protected fish during the eruption, but ultimately survival depended on the degree to which the chemical, physical, and biological conditions of the lakes were changed. Of particular importance were water-quality characteristics and the type and abundance of food items.

A conceptual diagram of fish response in blowdown-zone lakes is presented in Figure 12.8 (upper). Blowdown-zone lakes received large amounts of volcanic blast material and tephra and organic constituents of the shattered and pyrolized forest. The latter material included nutrients that enriched lake waters. Wissmar et al. (1982b) found greatly reduced water clarity in blowdown-zone lakes during June 1980 because of suspended material in the water column. However, Crawford (1986) reported that clarity of these lakes had greatly improved by late summer 1980, and Carpenter (1995) found that by 1990 water transparency was typical of undisturbed lakes of the region.

Crawford (1986) suggested the eruption had short-term effects on the aquatic food web as a result of decreased light penetration. He surmised that lowered light penetration as a result of suspended particles reduced primary producers, which in turn severely reduced the abundance of their zooplankton consumers, an important prey for fish. With improved light transmission, zooplankton numbers rebounded, and limited data suggest this process did occur. In St. Helens Lake, zooplankton (*Daphnia* spp.) were present at a density of 4 m^{-3} in 1980, and by 1981 they had increased to 2260 m^{-3}; during this period, cyclopoid copepods increased from 3 m^{-3} to 305 m^{-3} (Crawford 1986). Scharnberg (1995) studied the zooplankton in several of the blowdown lakes from 1992 to 1994 and found a diverse fauna composed of more than 50 species, including rotifers, copepods, and cladocerans. He noted that the zooplankton community structure of these lakes was influenced by the presence of fish and that highly palatable species (e.g., *Daphnia* spp. and *Bosmina* spp.) were lower in abundance when fish were present. Scharnberg (1995) compared zooplankton communities from Mount Rainier and Mount Hood with those of Mount St. Helens and concluded that zooplankton communities had largely recovered from the 1980 eruption.

Benthic insects often comprise an important component of trout diet in lakes. Crawford (1986) reported that deposition of tephra in lakes severely reduced bottom-dwelling insects but did not eliminate them. A wide array of invertebrate prey was observed in fish stomach samples during the first few years following the eruption. From 1980 to 1981, the dominant food item taken by fish was midge larvae, but by 1983 prey also included beetles, black flies, mayflies, caddisflies, stoneflies, dragonflies, and terrestrial insects (Crawford 1986). By 2000, additional insects were present in fish stomach samples, particularly terrestrial species such as ants, termites, and grasshoppers that were in greater abundance because of the colonization and growth of terrestrial vegetation. Phantom midge larvae (*Chaoborus* sp.) are large, mobile invertebrates that are often preferred prey of trout. These insects were present at much lower densities in lakes with fish compared to fishless lakes (Scharnberg 1995). Other food items that appeared in fish diets since the eruption were the signal crayfish (*Pacifasticus leniusculus*), amphipods (*Gammarus* spp.), and the northwestern salamander (*Ambystoma gracile*).

Results from fish stomach analyses suggest that plankton and insect prey were initially depressed but recovered quickly following the settling of suspended volcanic material. It remains unclear to what extent residual plankton and insects played a role in lake recovery relative to the importance of new colonists. The eggs and resting stages of zooplankton can persist for prolonged periods (Vogel et al. 2000) and are readily dispersed by wind or animals (e.g., dragonflies and waterfowl) (Maguire 1963). Most aquatic insects have highly mobile terrestrial life stages that are adept at colonizing new habitats (Merritt and Cummins 1996). Regardless of the contribution of residuals and colonizers, immediately after the eruption, enough prey was available to support some fish. Within a few years of the eruption, blowdown lakes supported a diverse prey assemblage.

The presence of suitable spawning substrates was also critical if fish were to persist in the blowdown lakes following the eruption. Crawford (1986) reported that, by 1985, successful spawning had occurred for brook trout in 3 lakes (Meta, Obscurity, and Shovel) and for westslope cutthroat in 1 lake (Lower Venus). Resident coastal cutthroat trout were observed spawning at Ghost Lake in 1983, and additional spawning may have occurred at other lakes during the first 5 years after the eruption. By 2000, natural trout reproduction was confirmed at 11 lakes, predominantly by brook trout (Lucas and Weinheimer 2003).

Trout populations in six lakes (Boot, Forest, Grizzly, Holmstedt, Ryan, and Snow) apparently experienced complete mortality during the May 1980 eruption. The reason fish perished from those lakes is unknown, but lake depth may have played a key role, given that four of the lakes where fish mortality was complete were among the shallowest lakes (maximum depth, less than 6 m). Boot Lake is both deep (21 m) and fairly large (6.5 ha), so reasons other than depth and size were responsible for fish extirpation there. Crawford (1986) noted that Boot Lake remained very turbid because of a large inlet stream that carried high sediment loads into the lake for several months after the eruption and speculated that turbidity was responsible for fish mortality. Ryan Lake, a shallow body of water that was ice free at the time of the eruption, was more severely disturbed than other blowdown-zone lakes. Dahm et al. (1983) reported lethally low oxygen levels in the epilimnion of Ryan Lake during August 1980 and total anoxia in deeper water.

During the first 20 years following the eruption, breeding fish populations were observed in all 13 lakes in the blowdown zone where they had survived the initial eruption. Three apparent colonization events occurred between 1980 and 2001. Brook trout appeared in Forest Lake in 1993 and in Ryan Lake in 2001. It is very likely that anglers transplanted these fish. Rainbow trout were captured in Little Venus Lake in 1993. These fish probably originated from fish stocked in nearby (upstream) Venus Lake in 1989. The only documented species extirpation in the 20 years following the eruption has been the loss of westslope cutthroat trout (a nonnative subspecies) from Venus Lake. In addition to these lakes, 8 other blowdown-zone lakes were stocked by Washington Department of Fish and Wildlife since the eruption (Lucas and Weinheimer 2003).

By 2000, fish populations were present in 15 of 18 blowdown-zone lakes thought to be capable of supporting fish. Three lakes in which fish were absent, but that could probably support fish, were managed in a fishless condition in accordance with the Mount St. Helens National Volcanic Monument Comprehensive Management Plan (USDA Forest Service 1985). Brook trout populations in 10 lakes were present at high densities, and individuals typically grew slowly. Westslope cutthroat and rainbow trout were present in 4 and 3 lakes, respectively. These fish had limited spawning success and were probably not capable of sustaining themselves for more than 10 years in the absence of stocking. Resident coastal cutthroat trout occurred in only one location, Ghost Lake, where they maintained a viable population. Brown trout were found in a single lake (Elk), where they required stocking to persist; lake trout were self-sustaining only in St. Helens Lake.

12.3.2.3 Spirit Lake

Spirit Lake was the most severely impacted lake during the 1980 eruption. The debris avalanche slid into the lake, displaced the water, and dramatically altered the basin morphology. In the aftermath, the lake's surface elevation increased by approximately 60 m; its surface area increased by 80%; its depth was greatly reduced; and new, large shoal areas were created. Thousands of tree boles and other forest debris floated on the surface, forming a large log mat. The once cold, oligotrophic water became highly enriched.

Spirit Lake was sampled in 1983, and no fish were captured (Crawford 1986). During several dozen limnological surveys between 1983 and 1986, no fish were seen by several investigators. Similarly, no fish were observed along the southern shoreline during littoral-zone surveys from 1982 through 1988 or during a snorkel survey in 1989. It was clear from these survey efforts and from the dramatically altered water-quality data (Dahm et al. 1981; Larson and Glass 1987; Larson 1993; Dahm et al., Chapter 18, this volume) that fish perished during or shortly after the eruption.

TABLE 12.2. Spirit Lake rainbow trout sample size (n), mean fork length, and mean weight for 2000–2002.

Year	Sample size	Fork length (mm)	Weight (g)
2000	62	519 (77)	1662 (548)
2001	16	544 (45)	2163 (643)
2002	73	565 (46)	2122 (429)

Standard deviations are in parentheses. Fish were captured by netting and angling.

In 1993, a single rainbow trout was captured in a gill net (Lucas and Weinheimer 2003). Return visits in 1994 and 1997 resulted in the capture of 1 rainbow trout each year. With the confirmed presence of fish, sampling efforts increased substantially, and 16 trips were made to the lake between 2000 and 2002. During these trips, 151 rainbow trout were captured by netting and angling (Table 12.2), 50.3% of which were males, 35.7% were females, and 14% were of undetermined sex. The age of 29 fish captured in 2000 was determined from otoliths and scales. Rainbow trout in the samples were present in three age classes: age 1+ (3.4%), age 2+ (13.8%), and age 3+ (82.8%), a very unusual age structure. The population appeared to be composed of few age classes and dominated by large fish (although the apparent age structure was likely influenced by sampling methods). Since 2000, a few age 4+ fish have been recorded.

Each of the major tributaries to Spirit Lake was either visually inspected for spawning adults or redds or electrofished for fry during the spring or summer of either 2000 or 2002. No evidence of spawning was found, and no fry were captured. Moreover, two snorkeling surveys, each several hours long, along the south end of the lake during 2002 failed to detect any small fish, although numerous large fish were observed. Reproduction has not been directly confirmed by observing redds or fry, but the presence of multiple age classes suggests successful reproduction has occurred or clandestine stocking has taken place.

Overall, there is a very limited amount of stream habitat available for spawning near Spirit Lake. The best spawning habitat is found in cobble- and gravel-dominated tributaries entering the lake from the north through the blowdown zone; but because of steep channel gradients (waterfalls or cascades), the length of streams available for spawning is small. Streams entering the lake from the south pass through the pyroclastic-flow deposits and carry high loads of fine sediment, yielding poor-quality spawning habitat. Fish may be spawning in the numerous springs on the lake bottom within the littoral zone. Gravel-sized pumice has sunk to the lake bottom and, in combination with cold, oxygenated springs, may provide suitable spawning sites. Numerous patches of bare pumice 0.5 to 1 m^2 in area observed in the densely vegetated littoral zone during 2002 may have been trout redds, but this suspicion has not been confirmed. The source of the Spirit Lake rainbow trout is unknown, but most likely they were illegally stocked.

Regardless of how trout entered the lake, they have recently found excellent conditions for growth, but major changes were necessary before the lake could support fish at all (see Figure 12.8, lower). In the aftermath of the 1980 eruption, the initial responses included greatly reduced light transmission because of suspended particles, elevated water temperatures, anoxia, and high levels of nutrients and reduced metals. The preeruption biota perished and was replaced by a prolific heterotrophic microbial community. Oxygen was depleted, and a rapid succession of biological, physical, and chemical transformations ensued (see Dahm et al., Chapter 18, this volume). By summer of 1982, heterotrophic bacteria had processed much of the fine organic matter, and inputs from rainwater and streams further diluted metal and nutrient concentrations. Reduction of particulates and solutes greatly increased water clarity, allowing light to penetrate several meters into the water column. Dissolved oxygen increased, and phytoplankton, zooplankton, and aquatic insects were starting to appear.

Spirit Lake's flora and fauna have changed considerably since the eruption. Immediately after the eruption, phytoplankton disappeared, but between 1983 and 1986, 138 species were present (Larson 1993). Zooplankton were observed in Spirit Lake in 1982, and high densities of rotifers were present by 1983 with fewer numbers of cladocerans and copepods (Dahm et al., Chapter 18, this volume). Zooplankton samples in 1986, 1989, and 1994 yielded rotifers, copepods, and cladocerans. *Daphnia pulex* and phantom midge larvae, both important fish prey, became very abundant. Aquatic insects, especially diving beetles (Dytiscidae), midges (Chironomidae), dragonflies and damselflies (Odonata), water boatmen (Corixidae), caddisflies (Trichoptera), stoneflies (Plecoptera), and mayflies (Ephemeroptera) all recolonized Spirit Lake from 1983 to 1986. These insects attained very high densities along Spirit Lake's southern shoreline, where the extensive shoal environment developed a species-rich and structurally complex macrophyte community dominated by pondweed (*Potamogeton* spp.). Several amphibians also recolonized Spirit Lake during the late 1980s, and the aquatic life stage of the northwestern salamander (*Ambystoma gracile*) was exceedingly abundant in the lake (Crisafulli et al., Chapter 13, this volume). The salamanders were readily preyed upon by large trout.

When fish colonized the lake in the early 1990s, a prey base was well established, and conditions promoted rapid growth. Water quality was favorable for salmonids, food was abundant, and predators were scarce; the rainbow trout population expanded quickly, and growth rates were high. The mean mass of age 3+ fish in 2000 was 2035 g ($n = 24$, SD = 226 g), a very large size for trout in their fourth year. Unfortunately, during the time of fish population growth, limnological measurements had largely ceased, and it is unclear how fish influenced food web dynamics. Fishing has remained closed in Spirit Lake, but natural predators have been observed in the area during the late 1990s, including the bald eagle (*Haliaeetus leucocephalus*), osprey (*Pandion haliaetus*), mink

(*Mustela vison*), and northern river otter (*Lontra canadensis*), and predation on trout has been observed. The fish population will likely continue to grow and be dominated by large fish into the early years of the 21st century, but eventually the lake's food web will likely return to preeruption conditions as the nutrient legacy from the eruption is diminished. At that point, the rainbow trout population will contain smaller individuals and will probably have a reduced standing crop.

12.3.2.4 New Lakes Formed by the Eruption

Coldwater and Castle lakes began to form when the May 18, 1980 debris-avalanche deposit dammed Coldwater and Castle creeks. Any fish in these new water bodies were recruits from tributary-stream populations or were intentionally stocked. Coldwater Lake was first surveyed in 1985, and no fish were captured or observed (Crawford 1986). During this same initial survey, a small segment of North Coldwater Creek was sampled to determine if fish had survived there, but no individuals were detected (Crawford 1986). Resident coastal cutthroat and rainbow trout as well as juvenile anadromous fish (steelhead, sea-run coastal cutthroat trout, and coho salmon) known to inhabit North Coldwater Creek in 1979 were all apparently killed by the eruption.

Coldwater Lake was assumed barren of fish until 1989, when about 30,000 under-yearling rainbow trout were stocked. Sampling conducted in the lake from 1990 through 2001 indicated a vigorous and healthy rainbow trout population had become established. Between 1997 and 2001, four or five age classes were present in the population. Most were 1- to 4-year-old fish and, in both 1998 and 2001, a few age 5+ individuals were also present (Lucas and Weinheimer 2003). During the 2001 survey, both westslope and resident coastal cutthroat trout were also captured (Lucas and Weinheimer 2003). It is possible that a few westslope cutthroat trout were inadvertently mixed with rainbow trout at the hatchery and stocked in the lake during 1989. The most plausible explanation for the presence of resident coastal cutthroat trout was that some individuals had survived the eruption in tributary streams and eventually colonized the lake. Lucas and Weinheimer (2003) report that the first evidence of trout reproduction was in 1992 when trout fry were observed in both Upper Coldwater Creek and South Coldwater Creek, and spawning trout were captured in the South Coldwater Creek during 1993.

Castle Lake was first sampled in 1985, and no fish were captured or observed there (Crawford 1986). Resident coastal cutthroat, rainbow trout, steelhead, sea-run cutthroat trout, and coho salmon that were known to be present in Castle Creek before the eruption were assumed to have perished during or shortly after the eruption. Rainbow trout were first seen in Castle Lake in 1991. These were apparently age 2+ hatchery fish (evidenced by their eroded dorsal fins) that emigrated from Coldwater Lake following the 1989 stocking and reached nearby Castle Lake through the Toutle River system. Subsequent sampling of Castle Lake in 1993 and from 1995 to 2001 revealed only rainbow trout. During this time, the population consisted of at least three and sometimes four age classes (Lucas and Weinheimer 2003). Growth appeared to be greatest during the first few years after introduction (1991 to 1993) and then declined somewhat from 1995 to 2001. The average fork length and weight of trout from 1997 to 2001 were nearly identical for Castle and Coldwater lakes, suggesting similar productivity levels within these new lake systems. Lucas and Weinheimer (2003) found numerous rainbow trout fry in Castle Creek during 1991 and 1993, confirming successful spawning.

Colonization of the new lakes by other native species required either the movement of fish from the Toutle River into the upper drainage network or deliberate human introductions. It is possible that a few resident coastal cutthroat trout survived in headwater streams and later founded the population in Coldwater Lake. Movement of anadromous fish into Coldwater and Castle lakes was limited by the sediment-retention structure located downstream on the North Fork Toutle River; however, migrating adult fish are captured and transported above the dam and may be able to reach Castle Lake. Coldwater Lake possesses a barrier to upstream fish movement at its outlet channel. In contrast, Castle Lake does not have impediments to fish colonization, and steelhead and coho salmon passed over the sediment-retention structure have access to the lake.

When Coldwater and Castle lakes were forming from 1980 to 1983, limnological conditions of these waters were not suitable for trout (Dahm et al. 1981; Wissmar et al. 1982b). By 1989, when rainbow trout were first stocked in Coldwater Lake, water quality had greatly improved. Secchi-depth readings of 7.0 to 8.0 m were recorded during 1989 and 1990 (Dahm et al., Chapter 18, this volume), indicating high light transmission into the water column. By 1989, oxygen levels within the epilimnion were also suitable for trout. Kelly (1992) found a diverse and abundant phytoplankton flora in both lakes in 1989. During that year, zooplankton reached high densities (up to 3088 m^{-3}), and the zooplankton community included 28 cladoceran, copepod, and rotifer species. *Daphnia* were the most common zooplankton. Additionally, by 1989, the aquatic insect community in Coldwater Lake was typical of lakes of the region. Crisafulli et al. (Chapter 13, this volume) found aquatic forms of the northwestern salamander in both Castle and Coldwater lakes.

Coldwater and Castle lakes developed water-quality conditions, aquatic invertebrate communities, and spawning habitats that supported self-sustaining trout populations within 10 years of the eruption, but the length and weight of fish has decreased during the decade since initial stocking. This decline may have been a response to reduced nutrient levels that were initially elevated following the eruption, or it may have been a compensatory response to the increasing number of individuals. In either case, the size of fish may be expected to decrease further in the coming years.

12.4 Summary

As mobile aquatic organisms, fish depend on an interconnected network of streams and lakes to fulfill many of their life-cycle needs. The impact of the Mount St. Helens eruption on aquatic systems was not uniform. Some streams were virtually devastated while others were barely affected. Existing lakes were altered by inputs of nutrients, tephra, and wood, and new lakes were formed. Human activities influenced fish recovery through stocking programs and creation of sediment-control structures through which fish movements were impeded or blocked. The extensive timber-salvage operation and planting on private and some public lands altered the composition of upland and riparian plant communities and changed posteruption forest succession, thus affecting the amount and types of organic matter available to some streams and lakes. All these activities made it difficult or impossible to conduct controlled field experiments on the recovery of fish populations after the eruption. Even so, there are common patterns in the ecological processes that have influenced fish at Mount St. Helens in the aftermath of 1980.

1. Two decades of monitoring have shown that changes in the trophic structure of streams and lakes can have a dominant influence on fish recovery in postdisturbance environments. The remarkable rebound of stream-dwelling fish populations, sometimes supplemented with salmon and steelhead of hatchery origin, in the food-rich conditions that prevailed in the late 1980s and 1990s demonstrated that even cold-water species such as salmon and trout could prosper in relatively poor habitats (high temperatures, scarce pools, and infrequent cover) if prey were abundant. Likewise, the proliferation of abundant, large trout in nutrient-rich lakes formed by the debris avalanche provides further support for the importance of food resources. The temporary abundance of certain types of food created by successional processes occurring in the first two decades posteruption has been largely responsible for the rapid recovery of fish at Mount St. Helens.
2. The type and intensity of volcanic disturbance have strongly influenced the rate of response toward ecological conditions typical of lakes and streams of the region. Streams and lakes in the tephra-fall zone and in the periphery of the blast area experienced little change, whereas those in the path of pyroclastic flows or inundated by volcanic mudflows were severely altered. The extent of damage to lake-dwelling fish populations was mediated by the amount of snow and ice cover at the time of the May 18, 1980 eruption. Had the eruption occurred at some other time of year or had the volcano not produced a large lateral blast, changes in streams and lakes, and their subsequent response rates, would have been quite different.
3. Finally, management activities have altered the response trajectory of native fish communities in many streams and lakes by changing riparian vegetation, sediment dynamics, and species distribution (through the introduction of non-native species and hatchery fish stocks). Unfortunately, the concurrent timing and spatial overlap of many of the management actions have made it impossible to evaluate the importance of each environmental factor separately. Some of the changes will probably be irreversible; however, the mosaic of managed and unmanaged watersheds, dammed and undammed rivers, and stocked and unstocked streams and lakes has created an unprecedented opportunity to compare long-term changes in fish across a landscape with a varied disturbance history, provided long-term monitoring programs remain in place.

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